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MEASUREMENT OF ICE FORCES ON FISHING VESSELS

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17. Abstract

A study has been conducted to investigate ice forces on fishing vessels. An instrumentation system, consisting of an array of 35 strain gauge pairs, was fitted into the bow of National Sea Products' "CAPE BRIER". The system monitored shear stress in the main frames of the instrumented panel and gathered data during significant impacts with ice. Data were converted to ice loads through an algorithm developed from finite element modelling and checked through a physical calibration. The maximum recorded ice pressure during a week of operating in ice was 644 kPa. Statistical analysis of the data indicates that potentially hazardous loads could be expected during the lifetime of the vessel.

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17. Résumé

Ce rapport concerne l'étude des efforts exercés par les glaces sur la coque des bateaux de pêche. A cette fin, un réseau de 36 paires de jauges extensométriques a été disposé sur une partie de la proue du CAPE BRIER, un bateau appartenant à National Sea Products. Il s'agissait de mesurer les contraintes de cisaillement dans les membrures du bateau et d'enregistrer le comportement de la coque sous l'impact de gros blocs de glace. La conversion des données en charges a été faite à l'aide d'un algorithme de modélisation par la méthode des éléments finis et les résultats ont été validés par étalonnage des éléments de mesure. La pression maximum enregistrée en une semaine a été de 644 kPA; l'analyse statistique des données a révélé qu'un bateau de pêche risquait de subir des impacts de niveau critique durant sa vie utile.

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TABLE OF CONTENTS

1. INTRODUCTION..1

2. SURVEY OF DAMAGE TO FISHING VESSELS........................2

   2.1 Present Occurrences of Damage to Fishing Vessels.......2
   2.2 Literature Search...7

3. DESCRIPTION OF OPERATING ENVIRONMENT AND SHIP PARAMETERS....9

   3.1 Physical Environment.....................................9

4. SELECTION OF HULL LOCATION FOR INSTRUMENTATION.............17

5. INSTRUMENTATION OF THE SELECTED HULL PANEL.................21

   5.1 Defining the Basic Measurement Quantity...............21
   5.2 Instrumentation Hardware................................25
   5.3 Data Processing...25

6. RESPONSE-TO-LOAD ALGORITHMS................................33

   6.1 Response-to-load Relationships.........................33
   6.2 Development of Transfer Matrices [T] and [T_1].........36

7. FULL SCALE PHYSICAL CALIBRATION............................45

8. ICE AND ENVIRONMENTAL DATA.................................55

   8.1 Approach and Methodology...............................55
   8.2 Environmental Conditions Encountered..................57
   8.3 Summary of All Data Collected..........................70
   8.4 Photographic Record.....................................74

9. ANALYSIS OF DATA...79

   9.1 General...79
   9.2 Pressure vs. Area and 3-D Plots........................79
   9.3 Extreme Value Statistics...............................91
   9.4 Expected Stresses..97
   9.5 Approach to Design Loads on Fishing Vessels..........102

10. CONCLUSIONS...105

11. RECOMMENDATIONS...107

12. BIBLIOGRAPHY..109

13. REFERENCES..111

TABLE OF CONTENTS CONTINUED

APPENDIX A - COMPUTATION OF MECHANICAL PROPERTIES OF SEA ICE

APPENDIX B - ENVIRONMENTAL LOG SHEETS

APPENDIX C - KEY TO AES CHARTS

APPENDIX D - DERIVATION OF BEAM SHEAR FORCE FROM STRAIN GAUGE RESPONSE

APPENDIX E - DERIVATION OF MATRICES [T] AND [T_1]

APPENDIX F - RESULTS OF THE PHYSICAL CALIBRATION

LIST OF FIGURES

FIGURE NO. PAGE NO.

2.1 LOCATION OF ICE DAMAGE TO FISHING VESSELS 4
2.2 SEVERITY OF ICE DAMAGE TO FISHING VESSELS 5
3.1 CLIMATIC DATA FOR PROJECT REGION 10
3.2 OCEANOGRAPHIC DATA FOR PROJECT REGION 11
3.3 SEA ICE LIMITS IN PROJECT REGION 13
4.1 MV CAPE BRIER BOW (STARBOARD VIEW) 18
5.1 LOAD SHEAR FORCE RELATIONSHIP FOR IDEAL BEAMS 22
5.2 PANEL GAUGING PATTERN AND RESULTING INFLUENCE AREAS 24
5.3 DATA ACQUISITION HARDWARE LAYOUT 26
5.4 Z80 MICROPROCESSOR SOFTWARE 27
5.5 Z80 MICROPROCESSOR DATA COLLECTION EXAMPLE 29
5.6 HP85B COMPUTER SOFTWARE 30
6.1 TYPICAL REPRESENTATION OF LOAD 34
6.2 FRAME 61½ FINITE ELEMENT MODEL 37
6.3 WEB FRAME 62 STRUCTURAL MODEL 38
6.4 SHEAR VIEW OF HULL MODEL 39
6.5 HULL STRUCTURAL MODEL 40
6.6 ALONG FRAME AND ADJACENT FRAME SHEAR FORCE DISTRIBUTION FOR TYPICAL INFLUENCE LOAD CASE 42
7.1 LOCATION OF CALIBRATION POINTS 46
7.2 SKETCH OF CAPE BRIER DRY TANK GAUGE CALIBRATION 47
7.3 FABRICATION SKETCHES 48
7.4 HEADER BAR GUSSET 49
7.5 MEASURED RESULTS OF THE 1 TON CALIBRATION LOADING OF SUB-PANEL 26 50
7.6 PREDICTED RESULTS OF A 50 KN CALIBRATED LOADING OF SUB-PANEL 26 51
7.7 PREDICTED RESULTS OF A 100 KN LOAD APPLIED AS A UNIFORM PRESSURE OVER SUB-PANEL 26 53
7.8 COMPARISON OF MEASURED AND THEORETICAL SUB-PANEL CALIBRATION LOADS AT SUB-PANEL #29 54
7.9 COMPARISON OF MEASURED AND THEORETICAL SUB-PANEL CALIBRATION LOADS AT SUB PANEL #26 54

LIST OF FIGURES
(CONTINUED)

FIGURE NO. PAGE NO.

8.1 ICE CONDITIONS FOR 18 MARCH 1984 58
8.2 ICE CONDITIONS FOR 20 MARCH 1984 59
8.3 ICE CONDITIONS FOR 22 MARCH 1984 60
8.4 ICE CONDITIONS FOR 25 MARCH 1984 61
8.5 SHIP'S LOG DATA - MARCH 19 62
8.6 SHIP'S LOG DATA - MARCH 20 63
8.7 SHIP'S LOG DATA - MARCH 21 64
8.8 SHIP'S LOG DATA - MARCH 22 65
8.9 SHIP'S LOG DATA - MARCH 23 66
8.10 SHIP'S LOG DATA - MARCH 24 67
8.11 SHIP'S LOG DATA - MARCH 25 68
8.12 NUMBER OF SUB-PANEL IMPACTS RECORDED ON THE CAPE BRIER 71
8.13 MAXIMUM SUB-PANEL ICE PRESURES MEASURED ON THE CAPE BRIER 71
8.14 MARCH 19 - OLD & NEW ICE 75
8.15 MARCH 19 - BREAKING PATTERN 75
8.16 MARCH 20 - OLD & NEW ICE 76
8.17 MARCH 20 - BREAKING PATTERN 76
8.18 MARCH 21 - NEW ICE 77
8.19 MARCH 21 - SEA ICE/ICEBERG 77
8.20 MARCH 25 - SEA ICE/ICEBERG 78
8.21 MARCH 25 - CUSP BREAKING IN THIN ICE 78
9.1 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 806 80
9.2 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 511 81
9.3 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 801 82
9.4 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 613 83
9.5 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 512 84
9.6 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 403 85

LIST OF FIGURES
(CONTINUED)

FIGURE NO. PAGE NO.

9.7 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 1204 86

9.8 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 408 87

9.9 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 1203 88

9.10 3-DIMENSIONAL AND PRESSURE/AREA PLOTS AT TIMES OF PEAK PRESSURE AND FORCE FOR EVENT NO. 1009 89

9.11 10 LARGEST PRESSURE/AREA CURVES FOR MAX FORCE AND PRESSURE 90

9.12 GUMBEL TYPE I EXTREME VALUE STATISTICS 92

9.13 GUMBEL TYPE II EXTREME VALUE STATISTICS 94

9.14 PREDICTED EXTREME PRESSURE/AREA PLOTS FOR TYPE I AND II DISTRIBUTIONS 96

9.15 LOCATION AND MAGNITUDE OF LOADS APPLIED TO THE FINITE ELEMENT MODEL 98

9.16 EXPECTED STRESSES AS A PERCENTAGE OF YIELD STRESS FOR MEASURED AND PROJECTED LOADS 99

9.17 THE ELEMENTS OF A CANTED ANGLE FRAME 101

LIST OF TABLES

TABLE NO.		PAGE NO.
3.1	INDUSTRY ESTIMATES OF ICE FLOE SIZE OFF NEWFOUNDLAND	12
3.2	GENERAL PARTICULARS OF THE CAPE BRIER	16
4.1	SUMMARY OF RELATIVE EXPECTED ICE LOADS (KN)	19
8.1	ENVIRONMENTAL DATA COLLECTED ON MV CAPE BRIER	56
8.2	SUMMARY OF PRESSURE AND ICE DATA	72

CONVERSION FACTORS

English to Metric (S.I.)			**Metric (S.I.) to English**		
FROM	MULTIPLY BY	TO FIND	FROM	MULTIPLY BY	TO FIND
	Length			**Length**	
inches	25.4	mm	mm	.0394	inches
inches	2.54	cm	cm	.394	inches
inches	.0254	m	m	39.4	inches
feet	.3048	m	m	3.28	feet
mi	1.609	km	km	0.621	mi
nmi	1.853	km	km	0.540	nmi
	Area			**Area**	
in^2	645.2	mm^2	mm^2	.00155	in^2
in^2	.000645	m^2	m^2	1549.9	in^2
ft^2	.093	m^2	m^2	10.75	ft^2
mi^2	2.59	km^2	km^2	0.386	mi^2
nmi^2	3.43	km^2	km^2	0.291	nmi^2
	Mass			**Mass**	
oz.	.0283	kg	kg	35.3	oz.
lb	.45	kg	kg	2.22	lb
	.00045	tonne	tonne	2222	lb
	.90	tonne	tonne	1.11	ton (short)
	.99	tonne	tonne	1.01	ton (long)
	Force			**Force**	
lb	4.41	N	N	0.227	lb
ton (short)	8.82	kN	kN	0.113	ton (short)
ton (long)	9.70	kN	kN	0.103	ton (long)
	Pressure			**Pressure**	
psi	6894.8	Pa	Pa	.000145	psi
psi	6.894	kPa	kPa	.145	psi
psi	0.0069	MPa	MPa	145	psi
psf	47.88	Pa	Pa	.021	psf

LIST OF SYMBOLS

A - area (m^2)
A_f - area of flange
A_w - area of web
b - frame span
E - Young's Modulus
F_{max} - Maximum ice force on panel during one impact.
$F(p)$ - probability that the measured pressure will be less than 'p' during a five minute sample.
h - height of web
I - identity matrix
$k(A)$ - Type II extreme value parameter (mode)
P, p - ice pressure (MPa)
P_{max} - maximum ice pressure over one sub-panel during one impact.
P_i - sub-panel loads
R - support reaction
$\{R_i\}$ - stringer reaction
R_u - estimated stringer reaction at sub-panels transversed by the stringer.
S - shear force
s - plate span
$[T]$ - transfer matrix
Tij - the applied hull (uniform) pressure load on sub-panel 'i' which causes a unit shear difference across sub-panel 'j'
t - plate thickness
t_f - flange thickness
t_w - web thickness
$UZ(A)$ - Type II extreme value parameters (mode)
u - subscript designating 'unit' loads
$u(A)$ - Type I extreme value parameter (mode)
V_A - transverse shear force (left)
V_B - transverse shear force (right)
$\{V_i\}$ - sub-panel shear differences
V_u - sub-panel shear difference due to the 'unit' load
$W(x)$ - applied beam load
x - position coordinate
z - section modulus
α - angle between frame and normal to plate
$\alpha(A)$ - Type I extreme value parameter (dispersion)
σ - yield strength

1. INTRODUCTION

Canadian fishing vessel's regularly operate in the ice off Labrador and have had a history of ice damage. To facilitate access to these and more northerly fish stocks, hull structure design and regulatory criteria are required. This study has taken the first steps toward this goal by measuring and analysing ice loads on a fishing vessel during operations in ice.

A system has been developed and implemented to allow the measurement of ice loads on a fishing vessel - National Sea Product's 'CAPE BRIER'. The system consists of an array of 35 strain gauges in the starboard bow dry tank, connected to an electronics package and a computer on the bridge. The system constantly monitors the gauges until a threshold is exceeded, at which time it collects five minutes of peak data.

The system was installed and calibrated, between voyages, at NSP's Lunnenberg facility. Due to a variety of circumstances (including a gas well blowout and a ship in distress) the system was only deployed in ice once. On that deployment valuable data was collected during a seven day period in ice. 86 five-minute data records were obtained, with a peak pressure of 644 kPa.

This report contains a complete description of the system, the calibration, the data collected, logs of the ice conditions and analysis of the data.

There are some important differences between the ice operations of fishing vessels and other commercial icebreaking ships. The 'CAPE BRIER' was only operated in pack ice conditions, never in continuous level ice. This along with the attitude of the master toward ice has a significant effect on the risk to the vessel. The report outlines the need for further data before rational design criteria can be formulated.

2. SURVEY OF DAMAGE TO FISHING VESSELS

2.1 Present Occurrences of Damage to Fishing Vessels

In order to determine the most effective location along the hull for the installation of the strain gauges, i.e. the area where most damage occurs, a survey of present damage patterns was conducted. This section presents the results of that survey.

(a) West Coast of Canada

The Department of Fisheries and Oceans were contacted (Irving, 1983) but were unaware of any damage to West Coast fishing vessels due specifically to ice. It was mentioned that skim or grey ice may be a problem to smaller wooden hulled crab boats, in the form of abrasion along the waterline, but again, no specific instances were available.

B.C. Packers were approached (Johnson, 1983), but were unaware of any present problem. When halibut were fished in Alaskan waters, there were some incidents of minor ice damage, but that fishery is now closed. The only other area where ice had ever been a problem was Tahsis Inlet, but since the herring fishery has also closed, there was now no problem.

Burrard/Yarrows Ltd., a ship repair facility was contacted (Tait, 1983) but were unaware of any damage due to ice.

United States Coast Guard in Seattle were approached (U.S.C.G., 1983) but were not aware of any damage worth reporting. All records regarding damage are passed directly to Washington for retention in data banks.

B.C. Cooperative, Prince Rupert, was suggested as an additional contact by B.C. Packers. Contact was made (Hill, 1983; Strand, 1983) but no damage incidents were recorded.

(b) MacKenzie River and Related Areas

Arctic Transportation Ltd., Calgary, were contacted (Wainwright, 1983; McLaren, 1983 and Friis, 1983) but as before there was no knowledge of damage due to ice. Mr. Friis was aware of some incidents of topside icing in the Beaufort Sea region, but these are not germane to this study.

(c) Great Lakes Region

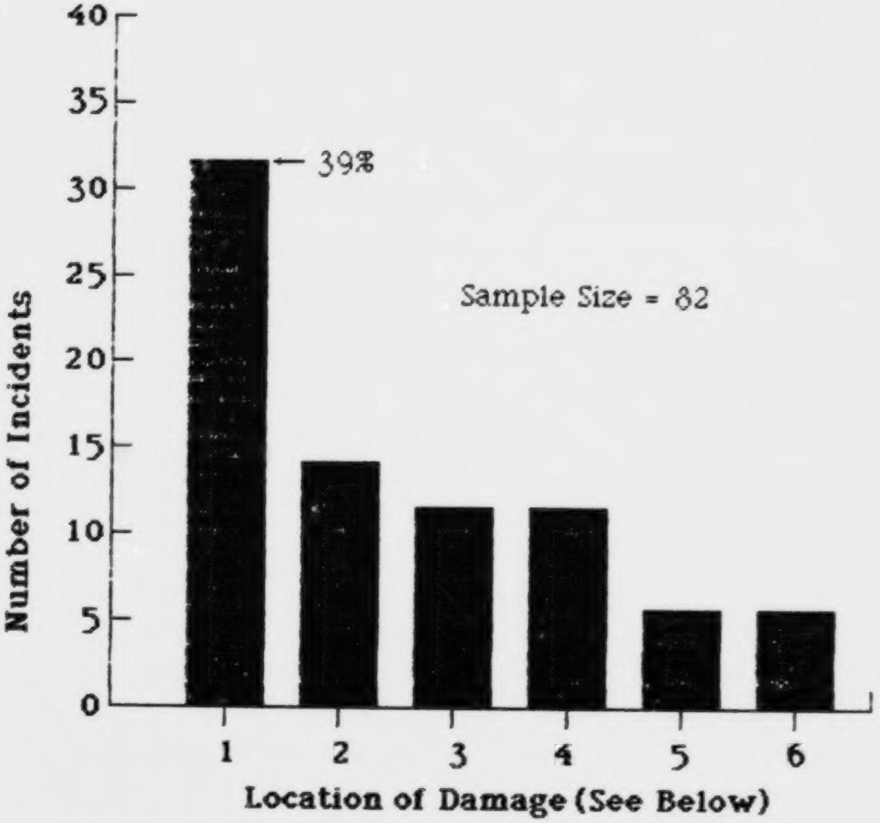
No enquiries were made from personnel from this area.

(d) East Coast of Canada

Lloyd's Register of Shipping, Montreal, provided a computer printout of ice damage by location and type that had been recorded on fishing vessels with which Lloyd's had been involved (Leighton, 1983). There were 35 vessels on this list since 1960, providing a total of 82 incidents. This set of data was incorporated into the results in Figure 2.1.

Department of Fisheries and Oceans, Halifax, provided a set of drawings and ice damage data (Cooper, 1983), for two classes of vessels; the Norway class and the Atlantic class. Both classes of vessels are operated by Fisheries Products Limited, St. John's. This data set included vessels and incidents. The data have been included in the results in Figure 2.2.

FIGURE 2.1 LOCATION OF ICE DAMAGE TO FISHING VESSELS



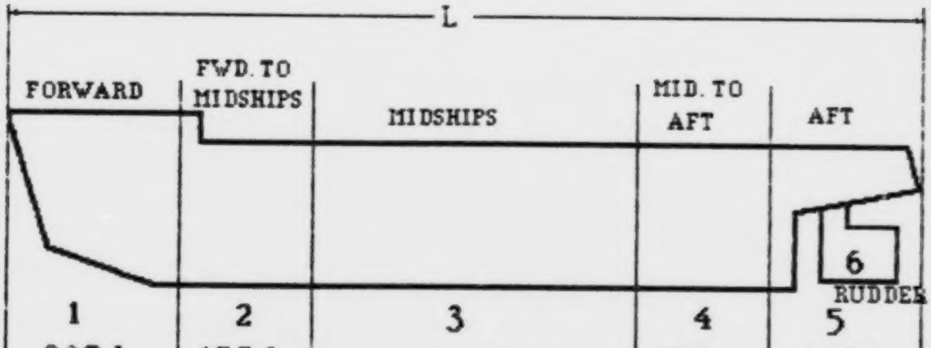
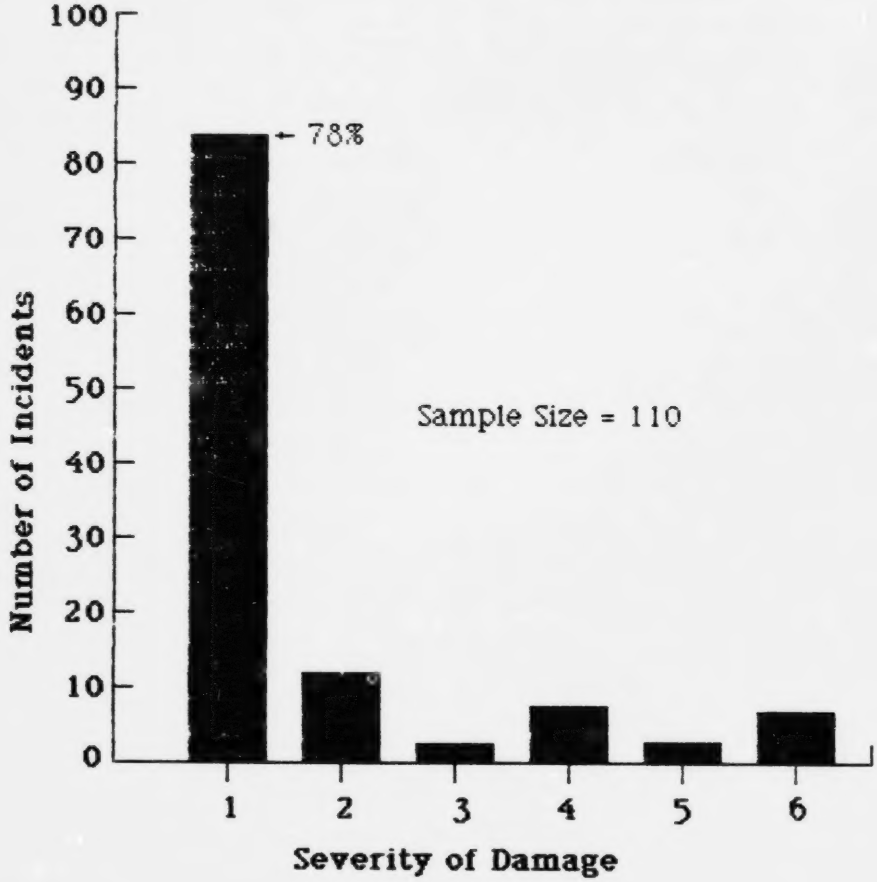

L
FORWARD
FWD. TO MIDSHIPS
MIDSHIPS
MID. TO AFT
AFT
6
RUDDER
1
20% L
2
15% L
3
30% L
4
15% L
5
20% L

FIGURE 2.2 SEVERITY OF ICE DAMAGE TO FISHING VESSELS



1 = Bent, Buckled or Indented
2 = Cracked or Fractured
3 = Leaking, Porous
4 = Torn, Holed or Collapsed
5 = Missing or Lost
6 = Rudder Damage (Twisted,Bent,Buckled or Indented)

Fisheries Products Limited, St. John's, were approached to provide some supplementary information to that contained in the drawings in the paragraph above (Hohoff, 1983). This was willingly given and the results in this section amended to suit the additional information. Mr. Hohoff described the uprating of the vessels for iceworthiness; initially the damage occurred immediately aft of the stem, and consisted mainly of shell plating indenting between the frames. Intermediate frames and thicker plating solved this "local" problem but moved the site of the damage further aft. Successive areas moving aft were strengthened so that now the complete waterline length is protected by a band with thick (18 mm) plate and intermediate framing. Mr. Hohoff believes that damage occurs in these fishing vessels now when in transit in and out of harbour where ice may be packed against the shore and harbour entrance.

Figure 2.1 shows the number of reported incidents of ice damage plotted against specific percentages of the ship's length; thus it is an indication of the number of ice damage incidents occurring on each portion of the ship's hull. Fifty-six percent of all reported ice damage incidents occur in the forward 35% of the hull with 39% in the forward 20%, while only 15% of the damage occurs in the middle 30% of the hull. The remaining 29% of reported ice damage occurs in the aft 35% of the hull including the rudder and stock assembly. It is clear that the majority of the reported ice damage incidents occur in the forward section of the hull. This would indicate that instrumentation to record ice loading should be placed within the forward thirty-five percent of the ship's hull.

Figure 2.2 plots the number of reported incidents of ice damage versus the severity of damage. From the graph, we can see that seventy-six percent of all reported ice damage is minor in nature, including bending, buckling or indentation of plating or frames. No failure of any structure occurs and no penetration by seawater takes place. Therefore, the majority of loading that occurs on the hull should be measurable within the linear range of strain gauge instrumentation, and a linear analysis F.E. model is justified.

2.2 Literature Search

2.2.1 Sources

As required in the contract a literature search for new information relating to ice damage to fishing vessels was made.

The sources of the literature search were:

(a) NTIS/EI
(b) Transport Canada Library, Ottawa
(c) Transportation Development Centre Library
(d) Department of Fisheries and Oceans Library
(e) C-CORE
(f) NORDCO (no response)
(g) College of Fisheries, Electronics & Navigation, St. John's, Newfoundland (no response)
(h) BSRA abstracts
(i) "Ships Navigating in Ice - A Selected Bibliography" TP 3855E
(j) Arctec Library

2.2.2 Subjects

The search was made on the following key words: fishing vessels, ice and ice loads. This search was designed to eliminate a full listing of sources of data concerning measurement of loads on hulls of all types of vessels, which has been performed before. All references found refer only to icing of fishing vessels.

3. DESCRIPTION OF OPERATING ENVIRONMENT AND SHIP PARAMETERS

3.1 Physical Environment

The test location lies roughly 200 miles off the coast of northern Newfoundland and southern Labrador, along the outer edge of the Grand Banks.

The seasonal climatic cycle in this region is influenced predominantly by a westerly circulation which brings relatively warm winds from the continent, and by the cold Labrador current flowing south along the coast from Baffin Bay.

3.1.1 Atmospheric Climate

Atmospheric climate data for the Grand Banks region are shown in Figure 3.1. This temperature has a relatively small annual range due to the maritime influence, and warms slowly during spring because of the sea ice which is present until late May or early June. Average air temperatures during the test period (March - May) range from 2 to 5°C. Mean wind speed during the same period is 15 to 20 knots and predominantly westerly in direction.

Visibility on the Grand Banks tends to be good in winter and low in summer when warm, continental air is cooled by the cold Labrador current. The test period is one of transition when poor visibility (< 0.5 n. miles) increases on average from 7 to 17% of the time.

3.1.2 Wave Climate

Wave climate data are shown in Figure 3.2. The second pattern of combined sea and swell wave height follows that of windspeed, with the minimum in June and July and maximum in December. Median values for the test period range from 1.5 to 2.2 metres, but extremes have been recorded which approach 20 metres. Wave heights will be considerably less in heavy pack ice.

Average recorded temperatures of the sea surface was nearly constant during the test period at 4°C. Water temperatures encountered during tests in the ice pack will be lower than this, in the range of 0 to -1°C.

FIGURE 3.1

CLIMATIC DATA FOR PROJECT REGION

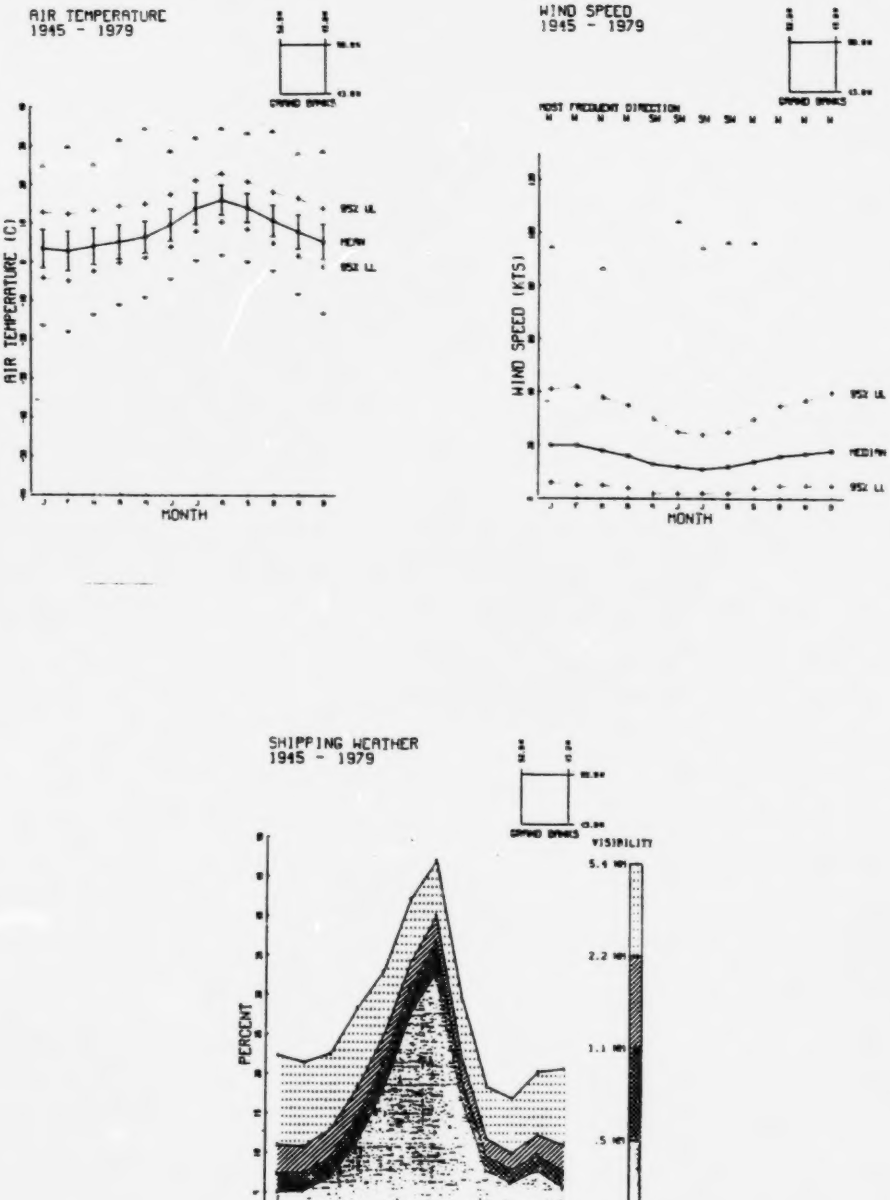
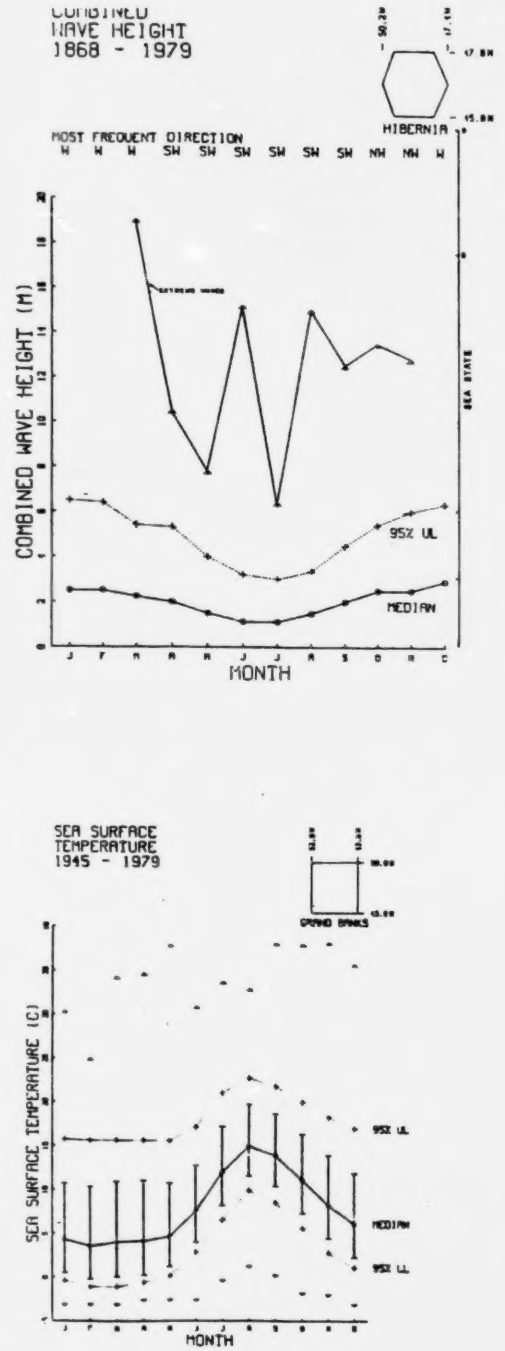


FIGURE 3.2

OCEANOGRAPHIC DATA for PROJECT REGION



Velocity of the Labrador current in this region is about 0.5 knots (U.S. Navy, 1974) flowing generally to the south east, although significant local eddies occur.

In summary, the expected environmental conditions during the tests are as follows:

- Air temperature near or above freezing with good visibility and 20 knot winds.
- Average wave height about 2 m and from the west, with water temperatures about 0°C.

3.1.3 Ice Climate

The test region is subject to sea ice during winter and spring and to icebergs year round. Median and extreme pack ice limits are shown on Figure 3.3. The nature of the pack ice is highly variable here. During winter it is composed mainly of locally formed ice, and grows to thicknesses governed by the length and severity of sub-freezing temperatures, wind velocity and snow covers. A typical maximum late winter thickness in the Strait of Belle Isle is 1.4m.

The pack can contain consolidated ice areas, but long term measurements indicate a predominantly small flow size as shown in Table 3.1 (personal communication, J. Benoit).

TABLE 3.1

INDUSTRY ESTIMATES OF ICE FLOE SIZE OFF NEWFOUNDLAND

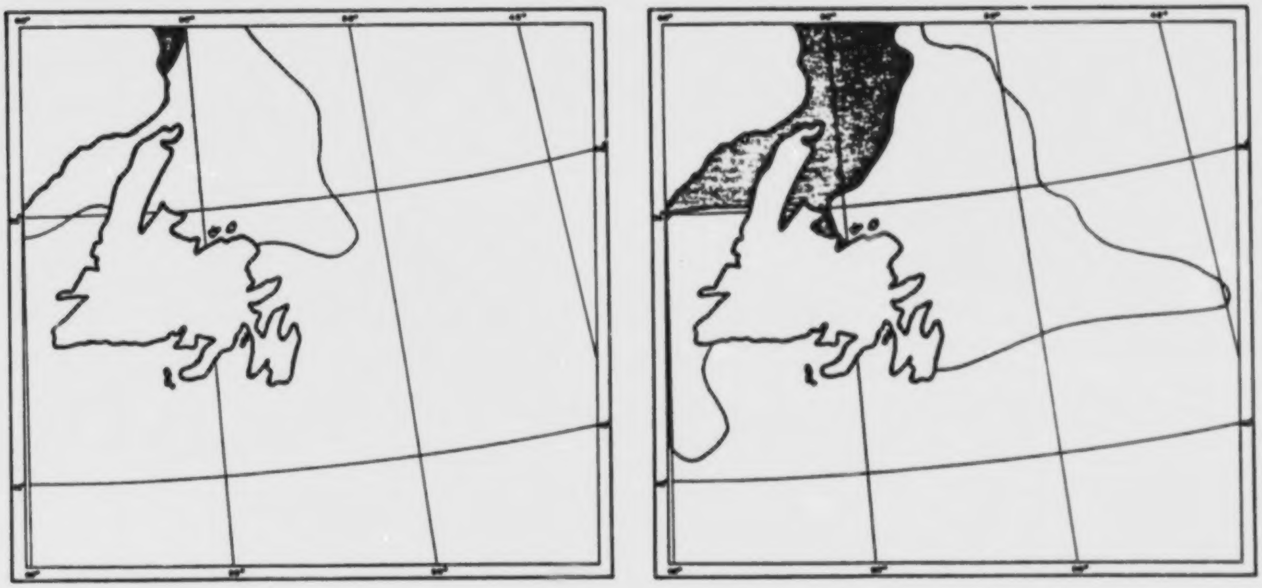
ICE CONDITIONS	SIZE RANGE (m)	PERCENT OF FLOES
OPEN PACK	10-20	96
	20-40	4
STRIPS OUTSIDE	10	91
PACK	10	9

FIGURE 3.3

SEA ICE LIMITS In PROJECT REGION

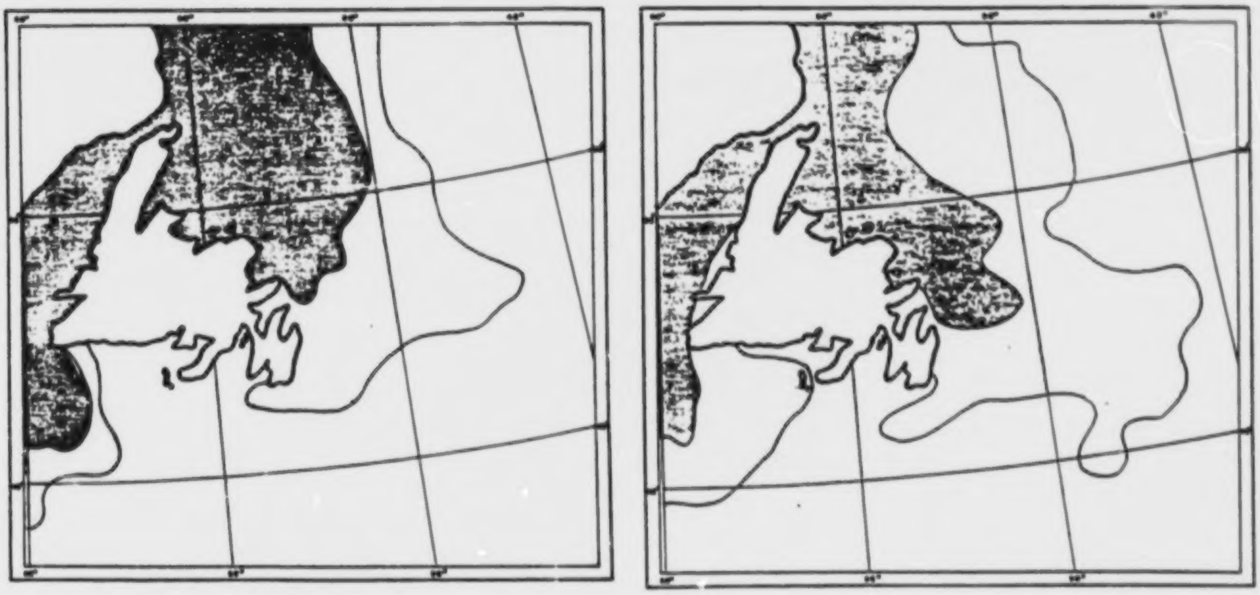
MAXIMUM OBSERVED LIMIT, 1963 - 1973 ☐

MEDIAN OBSERVED LIMIT 1963 -1973 ▨



December 25

January 29

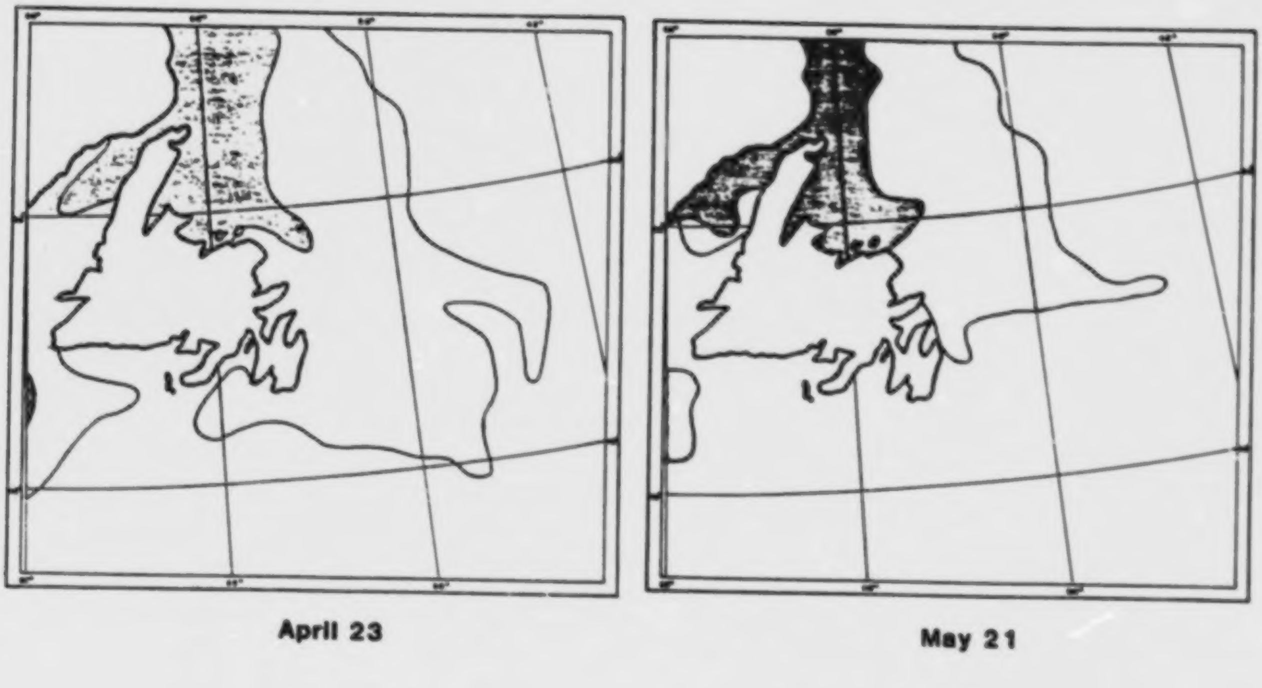


February 26

March 26

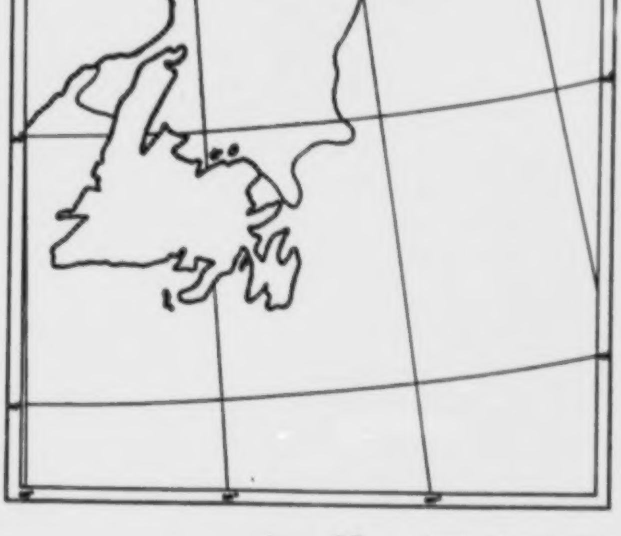
AFTER MARKHAM, 1980

FIGURE 3.3 (con't.)



April 23

May 21



June 18

AFTER MARKHAM, 1980

Concentration of the pack is also highly variable, depending on wind direction. Typically, the central offshore pack is in the range of 7 to 9 tenths cover during March (Markham, 1980), with a narrow band at the pack edge of varying concentration, and thin local streams of ice extending eastward for several miles.

A rule of thumb for the velocity of individual ice floes is 2% of windspeed or 0.4 knots in the project region. Floe velocity in close pack conditions will be less than this.

As the pack ice begins to melt and dissipate in April and May, thicker and older floes from northern Labrador Sea begin to drift with the Labrador current into the test region. Traces of multi-year ice up to about 2 metres thick can therefore be expected in late spring, although in very low concentrations.

Icebergs also occur in the test region during spring, when they are released from pack ice further north. Icebergs are not included in the test program, but could affect conditions under which tests are conducted. For instance, the CAPE BRIER might avoid or run at a reduced speed in areas of high iceberg concentration during poor visibility conditions.

3.1.4 Mechanical Properties of Sea Ice

Very few measurements of the mechanical properties of sea ice are publicly available for the test region, and those individual measurements do not provide a representative sample. More representative values can be obtained using numerical models which have been validated for a variety of test conditions. Suitable models have been derived by Michel and Touissant (1977) and Hiroshi et al (1978) for compressive strength and by Lane (1979) for flexural strength of sea ice. Details of these models and their assumptions are described in Appendix A.

Using the mean air temperature and assuming water temperatures of -1.8°C under the ice cover, the following values are obtained as seasonal maximums in the test region:

uniaxial crushing strength (kPa): FY 2800 MY Not available
flexural strength (Kpa): FY 223 MY 569

3.1.5 Description of the Ship

The ship selected for instrumentation, the MV CAPE BRIER, is a 50 metre stern trawler whose main features are indicated in Table 3.2. Note that she has been strengthened for service in ice covered waters. Her superstructure consists mainly of light transverse frames spaced at 600 mm (2 ft) with larger web type frames being used periodically along the ship. These frames are tied together longitudinally along the hull by stringers at various sizes and at various depths. Her typical operating displacement is around 1200 metric tonnes.

TABLE 3.2
GENERAL PARTICULARS OF THE CAPE BRIER

LENGTH OVERALL	49.9 m
LENGTH BP	42.0 m
BEAM MOULDED	11.80 m
DRAUGHT	4.13 m (worst operating)
DISPLACEMENT	1123 tonnes
BLOCK COEFFICIENT	.55
POWER	2000 BHP
SPEED (TRIAL)	13.5 knots
CLASSIFICATION	LR 100A1 + LMC (Hull = 1A Super)

4. SELECTION OF HULL LOCATION FOR INSTRUMENTATION

On the basis of damage information discussed previously, it was decided to locate the instrumented panel in the bow of the MV CAPE BRIER. The hull sections on two forward compartments, the "dry tank" and the "fore peak" were prime candidates since the water plane of the ship passes through them for the range of drafts under consideration. These are shown schematically in Figure 4.1. The final selection of the panel location was made on the basis of relative severity of the instrumentation environments as well as which hull area would experience the largest loads. The "dry tank" (either port or starboard) was environmentally more attractive since it was designed as a water-tight compartment, while the "fore peak" appeared damp in photographs.

The question of expected relative hull loads was investigated using an Arctec in-house computer program, ILOAD. Essentially, ice load at a given point on the hull is calculated using the model presented in [10], which computes load via a function of the form:

$$P = f(\text{ship geometry and displacement, ice conditions, impact velocities}) \tag{4.1}$$

Ship geometry can be generated from the work drawings, while information pertaining to design cargo loadings (i.e. displacement) can be obtained from the Trim and Stability Calculations booklet for the vessel.

For the purpose of the current analysis, four potential points of impact on the hull were selected as shown in Figure 4.1. Point numbers 1 and 2 are located at frame 63 (i.e. in the "dry tank") at the Load Water Level (LWL) and ballast water level (BWL) respectively. The other two points are located at frame 69 (i.e. in the "fore peak") at the LWL and BWL. Two "worst case" cargo loading conditions were chosen for comparison. Ice conditions for the calculation were taken to be expected values for the locations of fishing and forward ship speed was assumed to be 3 m/s. The results of the analysis are presented in Table 4.1.

FIGURE 4.1

MV CAPE BRIER BOW (Starboard view)

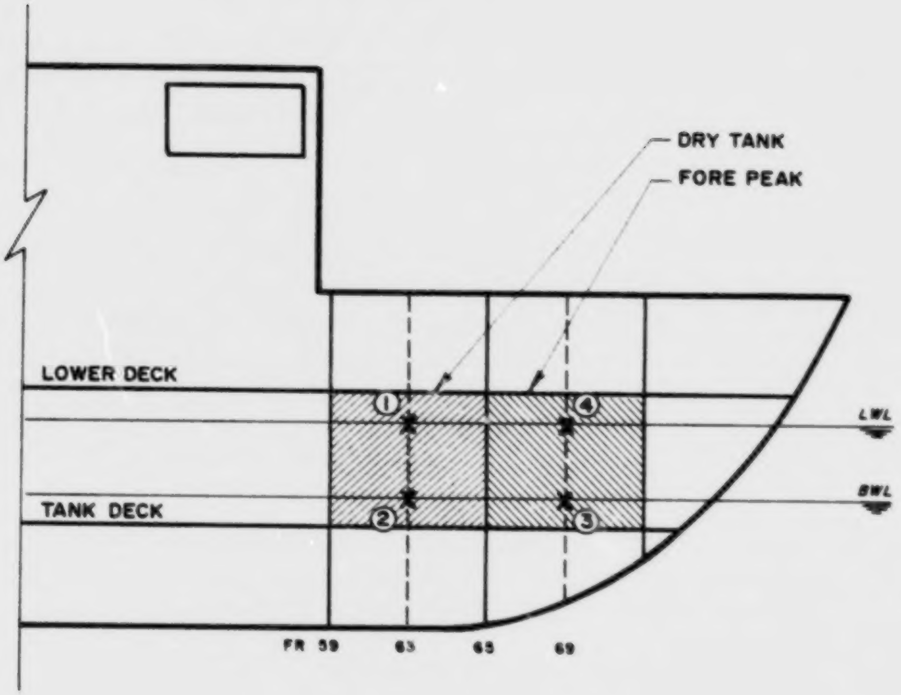

DRY TANK
FORE PEAK
LOWER DECK
TANK DECK
①
②
③
④
LWL
BWL
FR 59
63
65
69

TABLE 4.1

SUMMARY OF RELATIVE EXPECTED ICE LOADS (KN)

	LOCATION			
	DRY TANK		FORE PEAK	
	1	2	3	4
"WORST" DESIGN LOADING (SHIP IN ICE)	1170	890	150	2050
"WORST" DESIGN LOADING (SHIP NOT IN ICE)	1150	870	150	2010

It can be seen that the highest loads are predicted for hull ice impacts at the "fore peak" at the LWL. However, loads of a similar order of magnitude are predicted for the "dry tank". Since the dry tank is the less hostile environment to instrument it was selected as the panel location. For the particular ship in question, the starboard dry tank was chosen as the location for the instrumented hull panel.

5. INSTRUMENTATION OF THE SELECTED HULL PANEL

5.1 Defining the Basic Measurement Quantity

It is clear from the working drawings of the ship that the transverse frames in the region of the dry tank (frames 59 to 64) may be considered as beams which are continuously welded to the hull plating. The only exception is frame 62 which is a comparatively large web frame.

In the case of an ideal beam, the total applied load acting between two cross-sections is equal to the difference in transverse beam shear at the two sections plus the effect of support reactions (if any). These are illustrated in Figure 5.1. Mathematically this may be expressed (as indicated in the Figure).

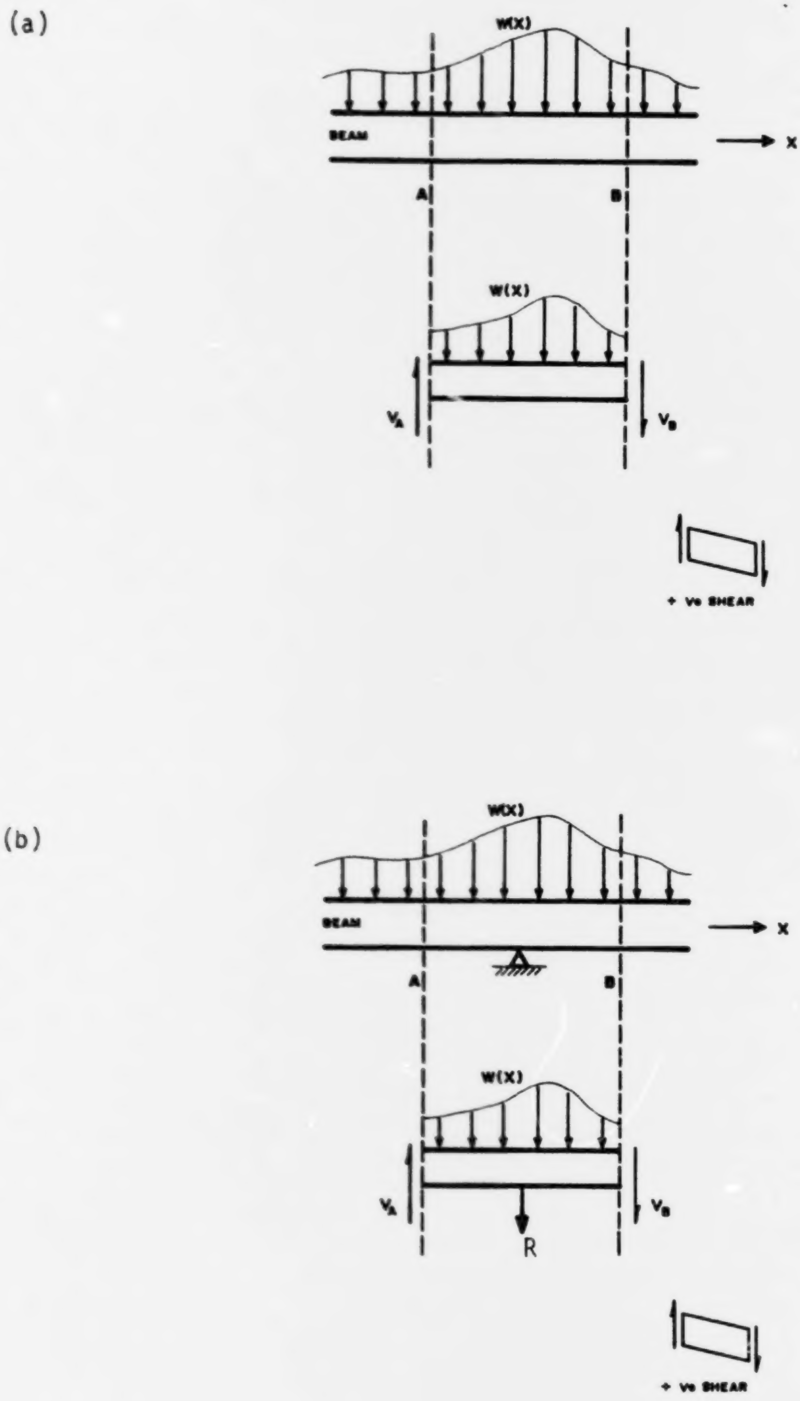
$$\int_A^B W(x)\,dx = V_A - V_B \quad \text{(no reaction loads)} \qquad (5.1a)$$

$$\int_A^B W(x)\,dx = (V_A - V_B) - R \quad \text{(1 reaction load)} \qquad (5.1b)$$

where $W(x)$ is the applied beam load, R is the support reaction (if any) and V_A and V_B are the transverse shear forces at the left and right ends of the interval respectively. The positive sense of shear is also indicated in the Figure. We note that in these ideal cases, the effect of the load on shear differences is entirely local in that an apparent shear difference between two beam cross sections is due only to a load applied between the two sections and/or some sort of support reaction (if present).

FIGURE 5.1

LOAD-SHEAR FORCE RELATIONSHIP FOR IDEAL BEAMS


(a)
W(X)
BEAM
x
A
B
W(X)
V_A
V_B
+ Ve SHEAR
(b)
W(X)
BEAM
x
A
B
W(X)
V_A
V_B
R
+ Ve SHEAR

(a)

$$\int_A^B w(x)dx = V_A - V_B$$

(b)

$$\int_A^B w(x)dx = (V_A - V_B) - R$$

In the hull structure of the ship under consideration, the beams (frames) are not quite ideal since they are tied to the adjacent frames through the hull plating. Hence apparent shear differences along any given frame will be due, at least in part, to cross frame influences. In the present case it will be shown that in general, these cross frame influences are small.

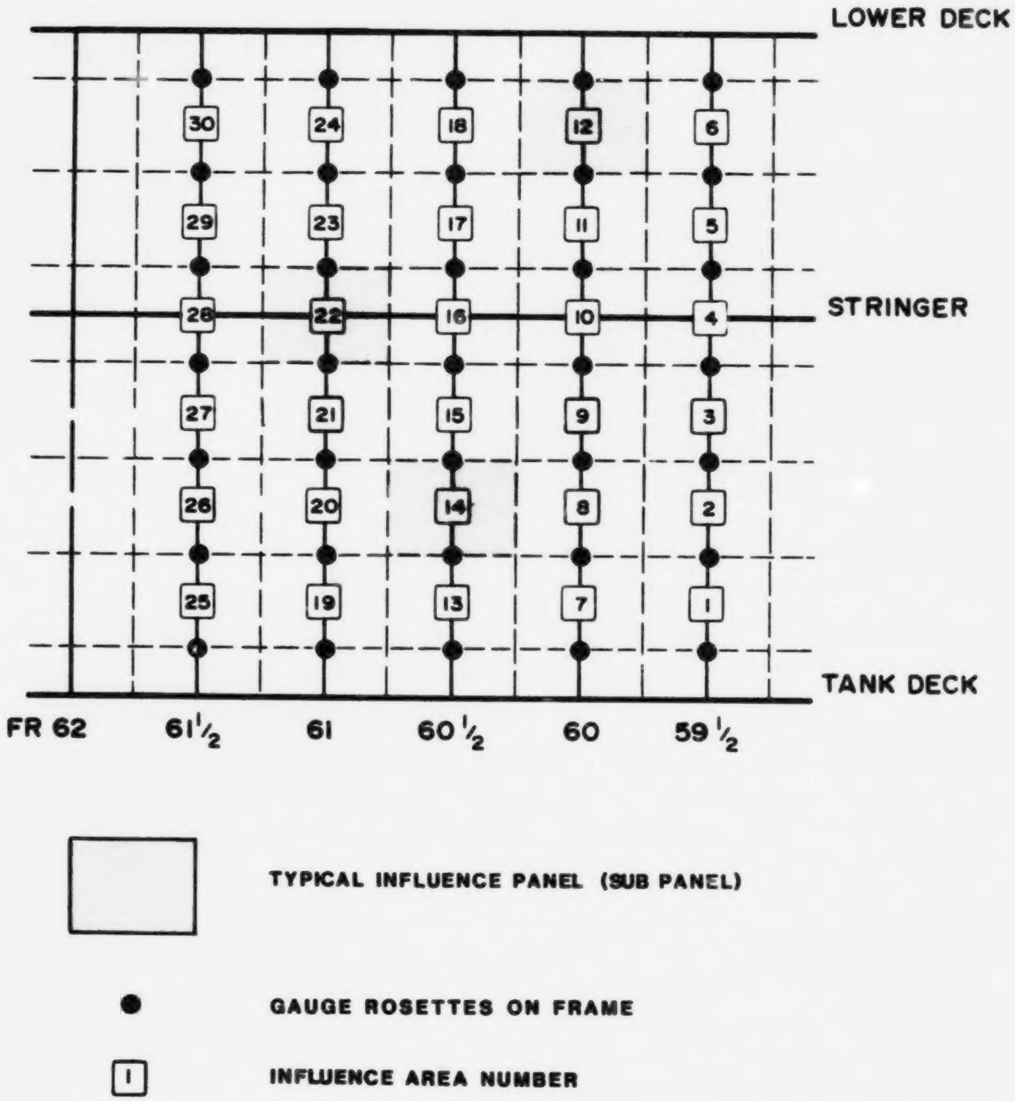
In light of the relatively localized connection between applied hull load and shear difference in the frames, it was decided to instrument frames with strain gauge rosettes in such a way as to determine the shear force at regular intervals along the length. The details pertaining to the relationship of strain gauge output to shear force are discussed in Appendix D. Essentially the frame shear force, S, at a gauge location is given by:

$$S = \text{factor} \times \text{measurement} \tag{5.2}$$

where "factor" is a function of the geometric and elastic properties of the frame. In the present case, 5 frames (frames 59½, 60, 60½, 61 and 61½, spaced at 300 mm) were instrumented at approximately 325 mm intervals between the lower deck and tank deck. Gauge rosettes were situated at approximately the same level across the frames, three above the stringer and four below. This gauging pattern, along with the associated load influence tributary areas, is shown schematically in Figure 5.2. Each area is bounded by an adjacent pair of gauges and spans the tributary hull width of the frame. The difference between shear forces at adjacent gauge locations constitutes a sub panel (i.e. influence area") shear difference. Hence the 35 gauge rosettes define the 30 influence sub panels as shown in Figure 5.2.

FIGURE 5.2

PANEL GAUGING PATTERN and RESULTING INFLUENCE AREAS



LOWER DECK
30
24
18
12
6
29
23
17
11
5
STRINGER
28
22
16
10
4
27
21
15
9
3
26
20
14
8
2
25
19
13
7
1
TANK DECK
FR 62
61½
61
60½
60
59½
TYPICAL INFLUENCE PANEL (SUB PANEL)
GAUGE ROSETTES ON FRAME
1
INFLUENCE AREA NUMBER

5.2 Instrumentation hardware

As described in the original proposal, much of the electronic instrumentation was located within the same space as the strain gauging to minimize cable runs. Figure 5.3 illustrates the hardware layout with a Z80 based acquisition system in the bow and an HP85B desktop portable computer on the bridge. The two processors communicate through an RS-232 serial interface consisting of 2-4 conductor cables with 50% wire redundancy. The fibre optics interface, discussed in the original proposal, was not installed at this time due to time constraints. If environmental noise becomes a problem at some future date (very unlikely) then this fibre optics cable can easily be fitted.

5.3 Data Processing

There are two processors in this data acquisition system and each unit has its own software tasks.

In general the Z80 microprocessor in the bow space does the high speed, simple sorting tasks, while the HP85B does the slower, more sophisticated data sort, storage, preliminary analysis and CRT display tasks.

Figure 5.4 is a flow chart of the Z80 software, and Figure 5.5 illustrates the data processing result. The Z80 scans all strain gauges continuously at a loop rate of approximately 500 Hz maintaining a sum array and a peak-time-slice array for each of the 35 strain gauge channels. At the end of a five minute data acquisition period the Z80 transmits this data to the HP85B on the bridge via the serial interface.

The sum array is simply the sum of all measurements for each channel over the acquisition period. This array is used by the HP85B, along with the total number of samples taken, to calculate the average value of each strain gauge channel over the 5 minute period. These averages are used by the HP85B to assess gauge drift and gauge zeros.

FIGURE 5.3

DATA ACQUISITION HARDWARE LAYOUT

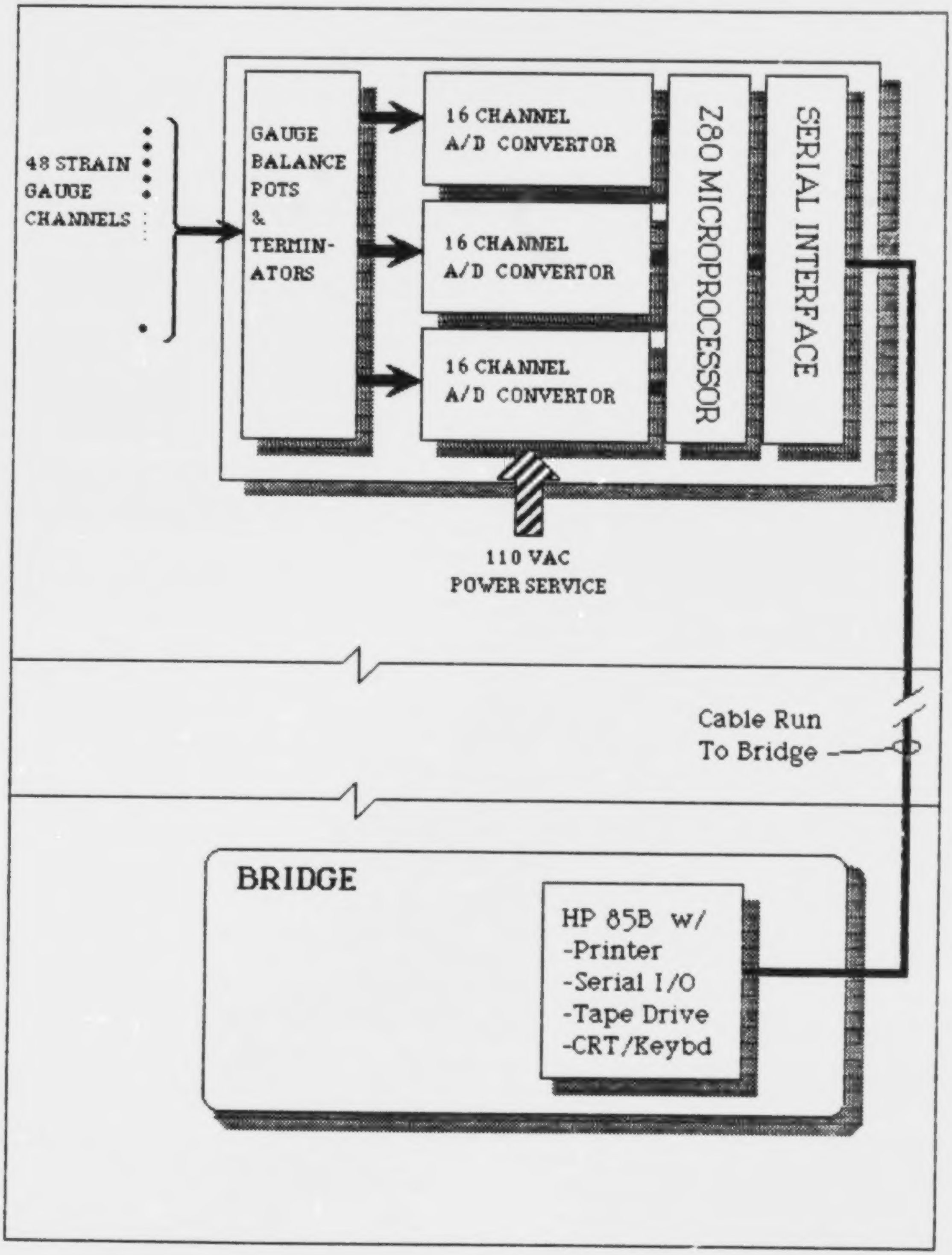
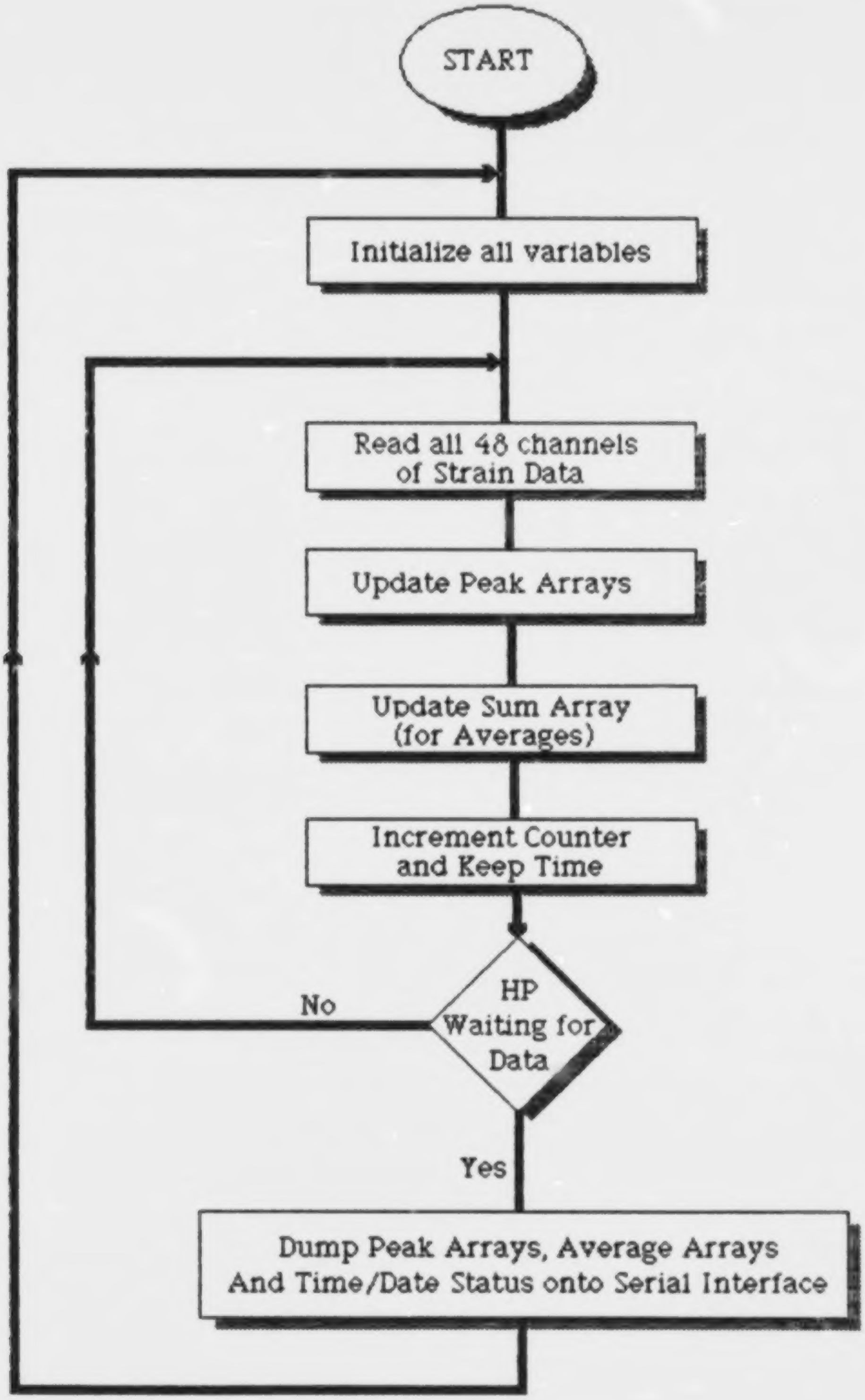

48 STRAIN GAUGE CHANNELS
GAUGE BALANCE POTS & TERMINATORS
16 CHANNEL A/D CONVERTOR
16 CHANNEL A/D CONVERTOR
16 CHANNEL A/D CONVERTOR
Z80 MICROPROCESSOR
SERIAL INTERFACE
110 VAC POWER SERVICE
Cable Run To Bridge
BRIDGE
HP 85B w/
-Printer
-Serial I/O
-Tape Drive
-CRT/Keybd

FIGURE 5.4

Z80 MICROPROCESSOR SOFTWARE


START
Initialize all variables
Read all 48 channels of Strain Data
Update Peak Arrays
Update Sum Array (for Averages)
Increment Counter and Keep Time
HP Waiting for Data
No
Yes
Dump Peak Arrays, Average Arrays And Time/Date Status onto Serial Interface

Each of the 35 channels will have obtained a maximum value sometime within the five minutes of data acquisition. This peak value, along with the instantaneous value of all the remaining 34 channels, is stored in the peak-time-slice array for that given channel. Thirty-five peak-time-slice arrays are created over the five minute period representing 35 distinct time-slices which one can analyze for total panel loading and active ice areas and pressures. For each time-slice a time will be logged so one can also analyze the sequence of these time-slice events.

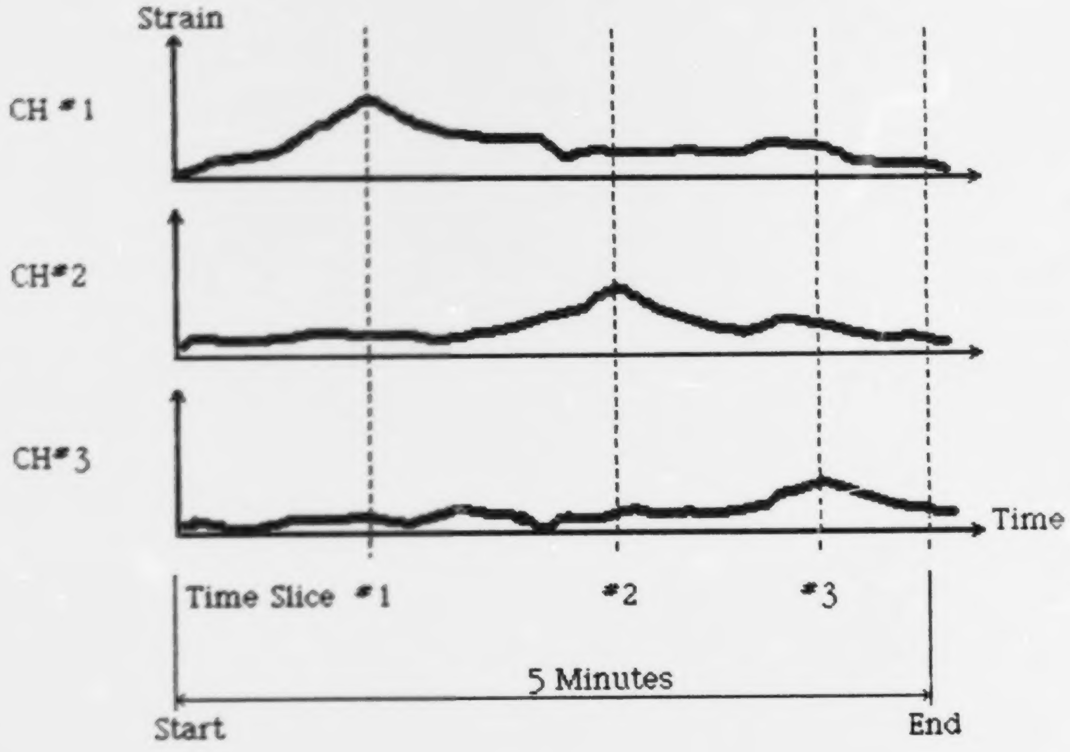
In many cases these peak-time-slice arrays will be of insignificant strain level and it is then up to the HP85B to decide if all, some or none of the strain data is worth storing onto tape. Figure 5.6 is a flow chart of the HP85B software. Once every five minutes the HP85B asks the Z80 for its raw data (sum array, peak-time-slice arrays, time sequencing) and then performs a number of checks to determine what data should be kept. The first check is to see if the peak values are very much larger than the average values for any of the channels. If the peak values are not larger than the zeros, then it is concluded that there was no ice activity during the last period of data collection. In this case the averages are used as the new gauge zeros and the CRT display is refreshed accordingly.

The second check occurs if ice activity is detected through the peak/average comparison. The peak values (after zero corrections) are compared to a set threshold (THRESHOLD_S) to determine the significance of the strains. If the peak strains are significant then the full data set from the Z80 (all peak-time-slice arrays) are stored on tape. If the peak strains are not significant then only the peak strains for each channel (no time slices) are stored on tape.

By separating the data into 3 categories only the important ice loads are stored on tape, permitting the HP85B to run unattended for days if not weeks (depending on ice loads) without requiring an operator to change cartridge tapes. Since no one really knows what loads to expect, it is understood that thresholds will be set low initially to assure a significant amount of data is collected. The setting of this threshold, tape changes and the logging of ice conditions were the primary responsibilities of the operator while the ship was in ice infested waters.

FIGURE 5.5

Z80 MICROPROCESSOR DATA COLLECTION EXAMPLE


Strain
CH #1
CH#2
CH#3
Time
Time Slice #1
#2
#3
5 Minutes
Start
End

On termination of the 5 minute period the microprocessor returns the peak and average strain for each of the 48 strain gauges. For each channels peak-value the strain level of all 48 channels, at the time the peak occurs, is also returned to the HP85B. As well, the times of each of the slices, relative to the start is returned.

FIGURE 5.6

HP85B COMPUTER SOFTWARE

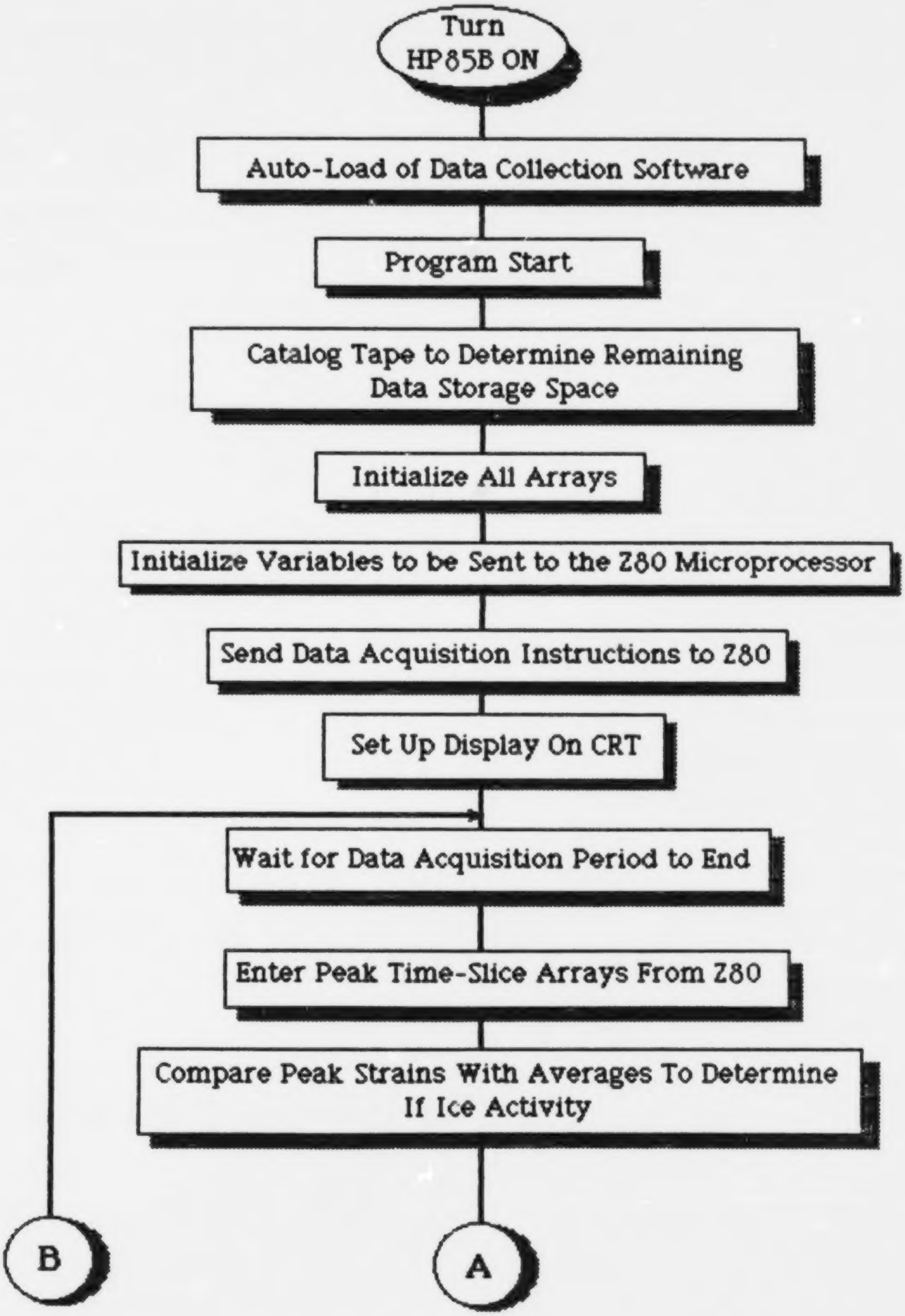
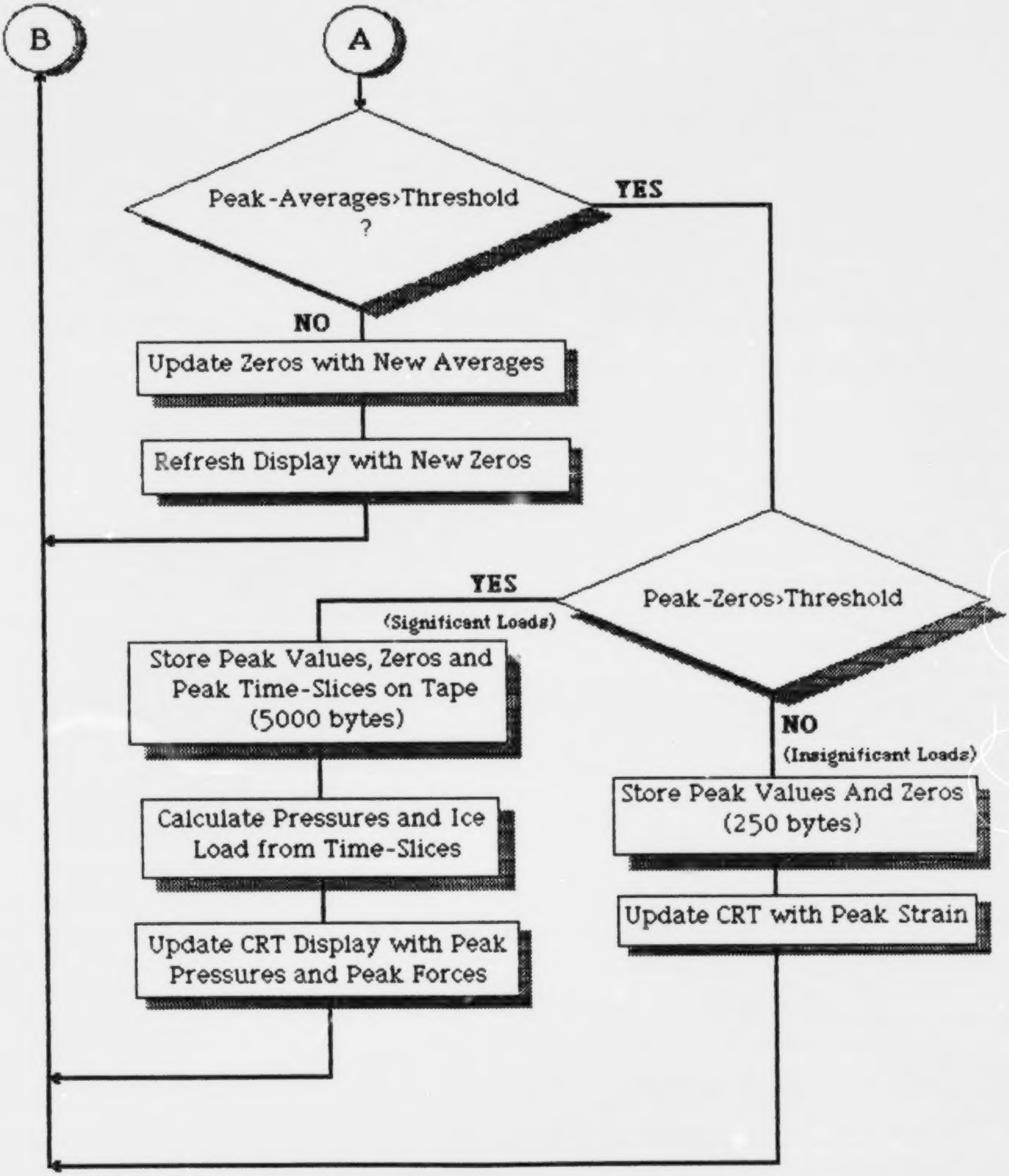

Turn
HP85B ON
Auto-Load of Data Collection Software
Program Start
Catalog Tape to Determine Remaining Data Storage Space
Initialize All Arrays
Initialize Variables to be Sent to the Z80 Microprocessor
Send Data Acquisition Instructions to Z80
Set Up Display On CRT
Wait for Data Acquisition Period to End
Enter Peak Time-Slice Arrays From Z80
Compare Peak Strains With Averages To Determine If Ice Activity
B
A

FIGURE 5.6 (CONTINUED)


B
A
Peak-Averages›Threshold ?
YES
NO
Update Zeros with New Averages
Refresh Display with New Zeros
YES
(Significant Loads)
Peak-Zeros›Threshold
Store Peak Values, Zeros and Peak Time-Slices on Tape (5000 bytes)
NO
(Insignificant Loads)
Store Peak Values And Zeros (250 bytes)
Calculate Pressures and Ice Load from Time-Slices
Update CRT with Peak Strain
Update CRT Display with Peak Pressures and Peak Forces

6. RESPONSE-TO-LOAD ALGORITHMS

6.1 Response-to-Load Relationships

A technique used successfully in the past [11] by Arctec to relate measured structural response to the loads which caused them is to approximate the real load by a collection of discrete sub-panel uniform loads as depicted in Figure 6.1. At an instant of time during impact, the actual load contours over the instrumented panel are approximated by the average load on each of the sub-panels as computed based upon the "basic" measurements.

As noted previously, a load applied to a particular sub-panel will cause strain gauge response at all the other sub-panels to some extent due to cross frame effects. In order to account for this the sub panel loads $\{P_i\}$ are related to the sub panel shear differences $\{V_i\}$ by the following linear matrix formulation based on equation 5.1b:

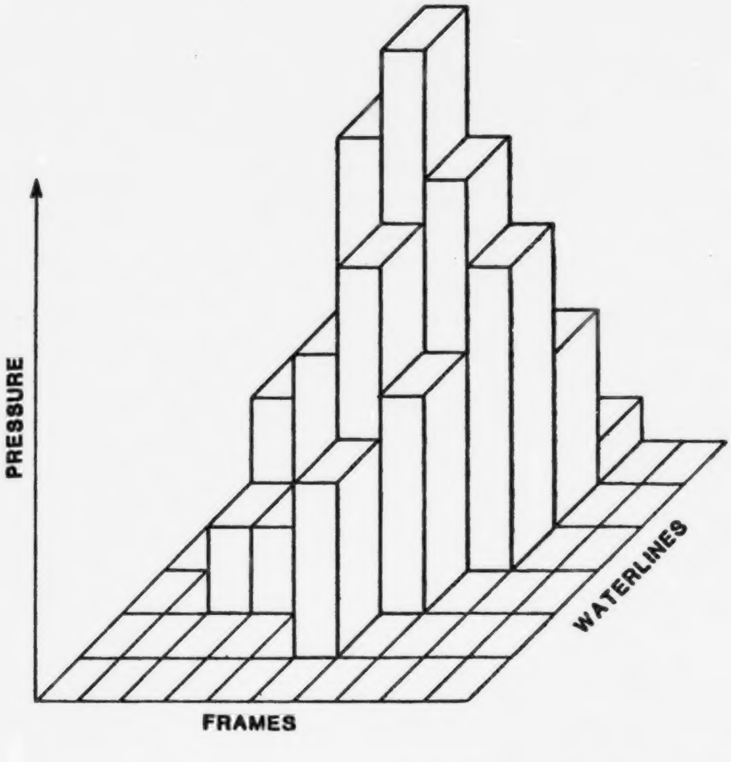
$$\{P_i\} = [T] \left(\{V_i\}-\{R_i\}\right) \qquad i = 1, 30 \qquad (6.1)$$

where R_i is the support reaction (e.g. stringer reaction), if any, acting on the i(th) sub-panel. The transfer matrix [T] is 30 x 30 and its elements are defined by:

T_{ij} = the applied hull (uniform) pressure load on sub-panel "i" which causes a unit shear difference across sub panel "j".

FIGURE 6.1

TYPICAL REPRESENTATION OF LOAD



It may be noted that in the present case the components of $\{R_i\}$ will be zero except at sub panels 4, 10, 16, 22, and 28. Since the structure is being assumed linear (i.e. anticipated ice loading is in the elastic range), the stringer reactions may be expressed as a linear matrix function of the sub panel shear differences:

$$\{R_i\} = [T_1] \quad \{V_i\} \tag{6.2}$$

The matrix $[T_1]$ is 30 x 30 with zero elements everywhere except at rows 4, 10, 16, 22 and 28. This will allow the shipboard calculation of equation 6.2 to be done by 5 vector inner products instead of 30. In addition, it is expected to be fairly diagonal since cross frame stringer reactions should be small at locations which are relatively distant from the location of the applied load. Similarly the transfer matrix [T] is expected to be heavily diagonal so that shipboard calculation involving multiplication by [T] may be approximated by a single vector inner product involving the diagonal. By substituting equation 6.2 into 6.1 the response-to-load relationship may be expressed:

$$\{P_i\} = \underset{\substack{\uparrow \\ \text{highly} \\ \text{diagonal}}}{[T]} \qquad \underset{\substack{\uparrow \\ \text{diagonal}}}{([I] - [T_1])} \qquad \{V_i\} \tag{6.3}$$

where [I] is the 30 x 30 identity matrix. The development of matrices [T] and $[T_1]$ is discussed in the following section.

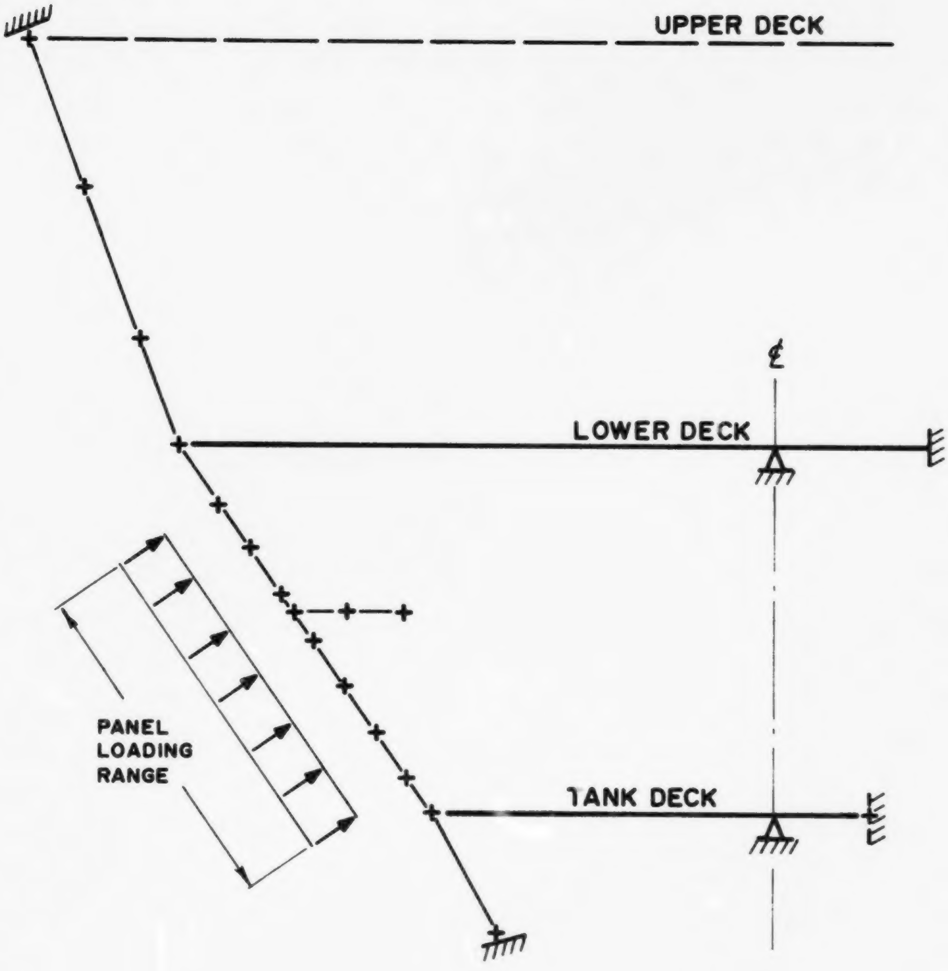
6.2 Development of Transfer Matrices [T] and [T_1]

Having defined the instrumented panel, its response to applied hull load is most conveniently studied using a finite element model. Noting that the frames in the panel of interest are structurally identical and geometrically very similar, it is appropriate to study the behaviour of one in detail and apply the results to all of them. In order to determine the cross frame influences it is necessary to model the behaviour of at least one adjacent beam as well. Provided that the influence across two frames is very small, it should not be necessary to model any more of the frames exactly. In this instance the STARDYNE structural analysis program was chosen to do the analysis.

In the present case, frames 61½ and 61 were selected as the central frame of interest and adjacent frame respectively. Frame 61½ was modelled using beam elements with geometry and section properties as given in the working drawings and is depicted schematically in Figure 6.2. Nodes were included at all gauge locations. It is considered fixed at the top (i.e. where it is welded to the upper deck) and at the bottom where it frames into the keel of the ship. At the centreline bulkhead, only rotation in the plane of the frame is allowed. The lower and tank deck portions of the frame are considered fixed at approximately 5/8 of their total breadth. Frame 61 was modelled according to its given geometric and section properties and with support conditions similar to frame 61½. Again nodes were included at all gauge locations. Web frame 62 was modelled using plate elements to reflect its massive structure and is shown in Figure 6.3. The peripheral frames (frames 62½ and 63, and frames 60½ and 60) were modelled according to their given geometry and section properties, but serve mostly to define the boundaries of the model. Frames 60½ and 62½ are fixed in displacement degrees of freedom, allowing moment transfer, while frames 60 and 63 are completely fixed. The hull surface was modelled by a network of triangular plates across the frames and is depicted in a shear view in Figure 6.4. The lower deck, tank deck and stringer were modelled using triangular and quadrilateral plate elements. A cut-away view of the assembled model is shown in Figure 6.5.

FIGURE 6.2

FRAME 61 1/2 FINITE ELEMENT MODEL


UPPER DECK
℄
LOWER DECK
PANEL
LOADING
RANGE
TANK DECK

STARDYNE FINITE ELEMENT MODEL PROJECTION ON X2-X3 PLANE CASE No. 5

FIGURE 6.3

WEB FRAME 62 STRUCTURAL MODEL

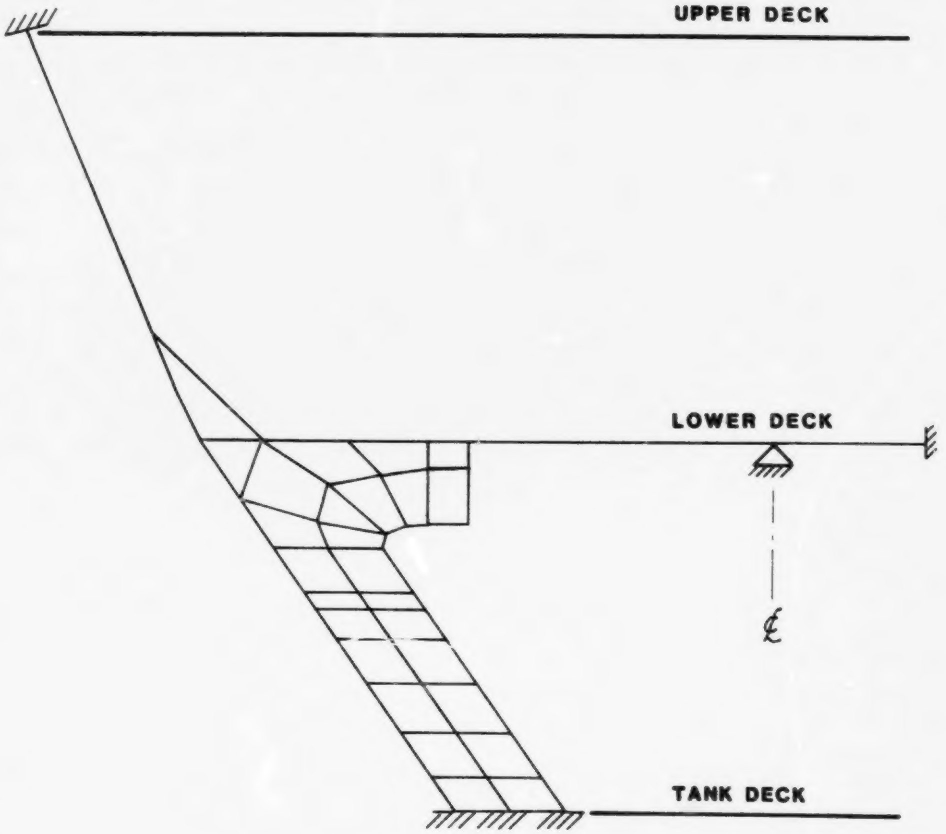

UPPER DECK
LOWER DECK
℄
TANK DECK

FIGURE 6.4

SHEAR VIEW OF HULL MODEL

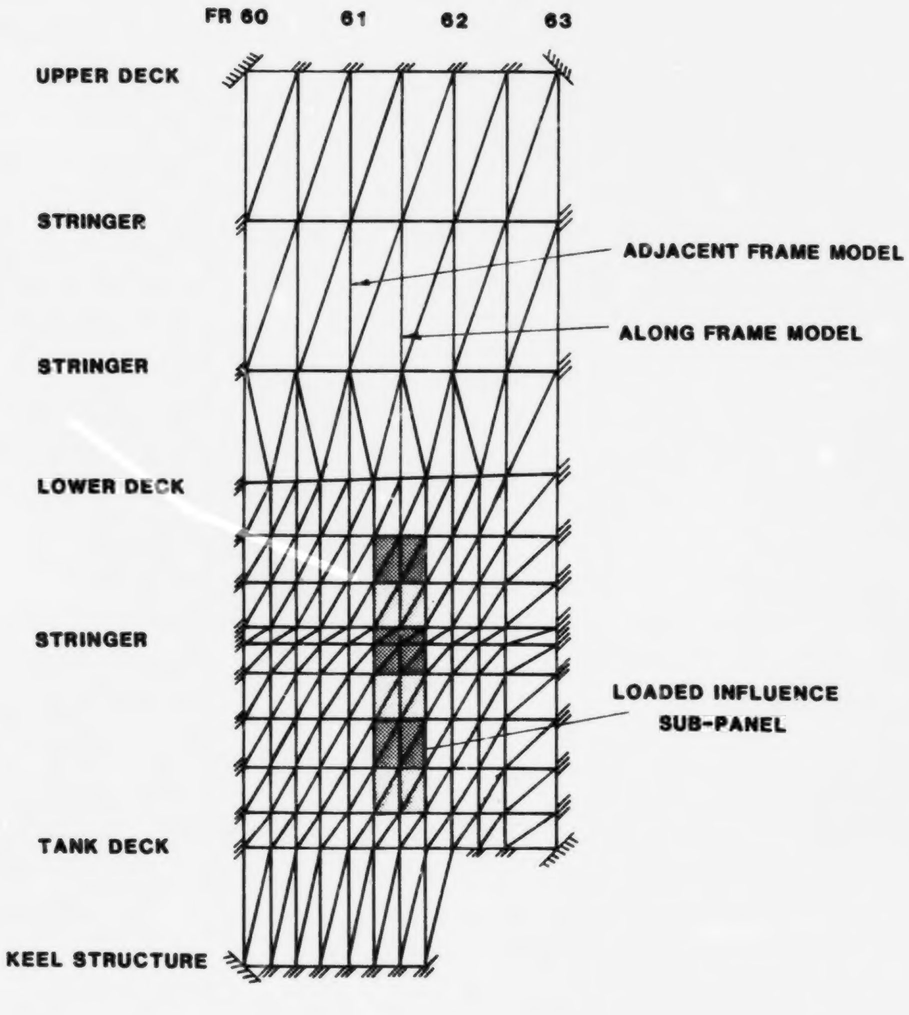
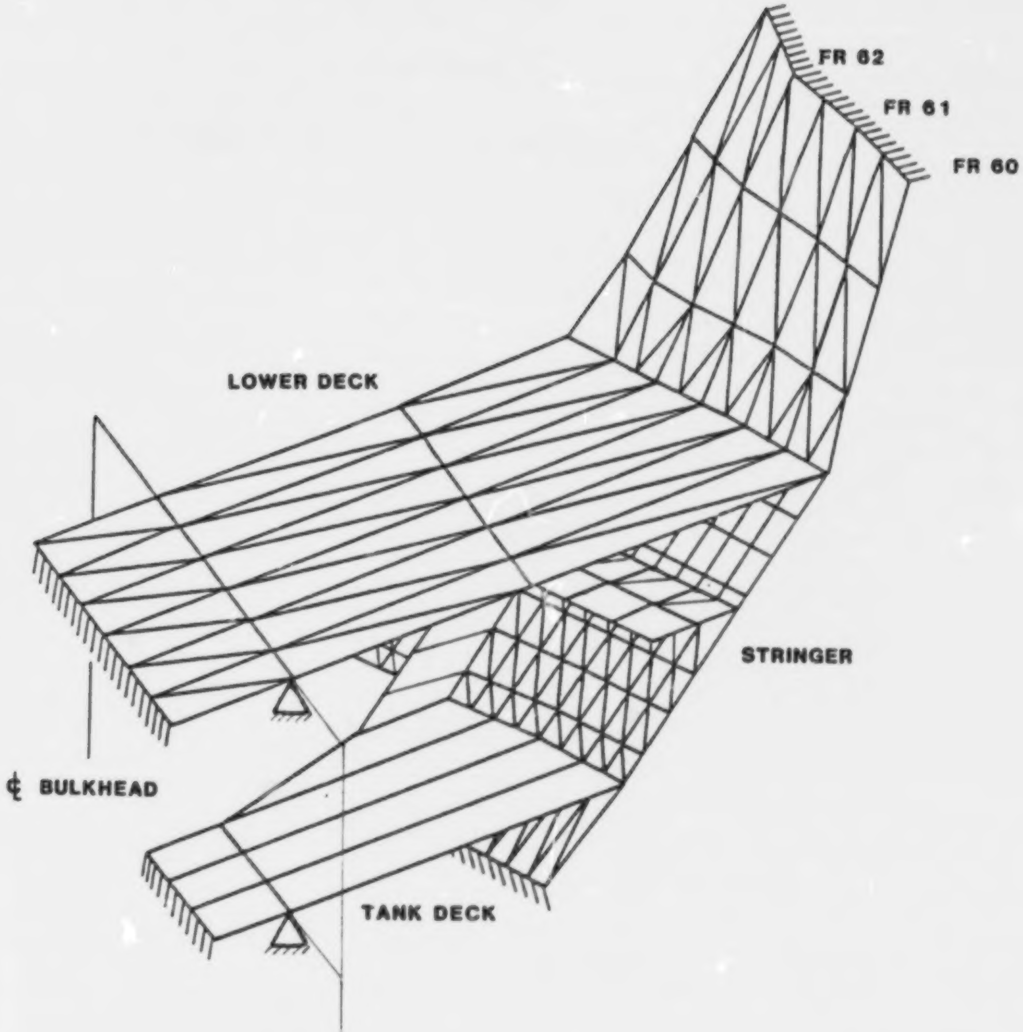

FR 60
61
62
63
UPPER DECK
STRINGER
ADJACENT FRAME MODEL
ALONG FRAME MODEL
STRINGER
LOWER DECK
STRINGER
LOADED INFLUENCE SUB-PANEL
TANK DECK
KEEL STRUCTURE

FIGURE 6.5

HULL STRUCTURAL MODEL


FR 62
FR 61
FR 60
LOWER DECK
STRINGER
℄ BULKHEAD
TANK DECK

Using this model, each of the six along frame hull influences areas (sub-panels 25 to 30) was subjected in turn to a "unit" load (i.e. a load of 100 KN applied as an average pressure). The resulting along frame and adjacent frame shear force distributions over the instrumented portion were noted. The along frame and adjacent frame shear distributions resulting from one such loading are shown in Figure 6.6. Note that the adjacent shear differences are relatively small except in the region of the applied load and at the stringer, which constitutes a reaction load on the frame. This corresponds to the shear behaviour of an "ideal" 2-D structure. This, together with the fact that the adjacent frame shears are typically an order of magnitude lower than the corresponding along frame values, suggests that the frames respond more or less independently to hull loads. Hence limiting the number of frames included in the model is justified.

From the results of the six "unit" influence loadings, two 30 x 30 matrices, V_u and R_u can be constructed. Details of this process are presented in Appendix E. Essentially the matrix V_u is composed of sub-panel shear differences due to the "unit" loads while the matrix R_u is composed of estimated stringer reactions at sub-panels traversed by the stringer. With these matrices formed, matrices $[T_1]$ and $[T]$ are given by:

$$[T_1] = [R\ ]\,[V_u]^{-1} \qquad (6.4)$$

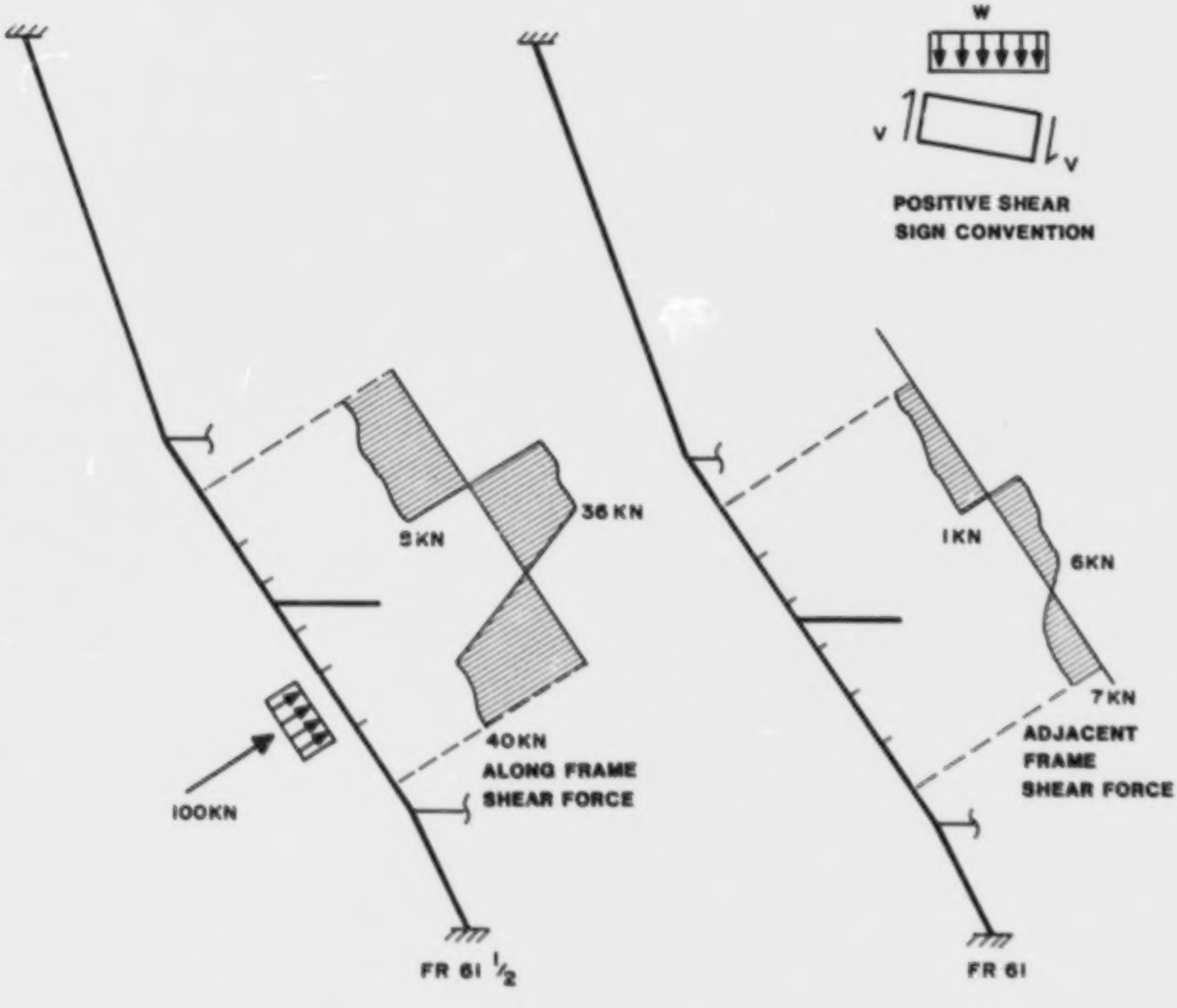
$$[T] = P_u\,[I]\,(\,[V_u] - [R_u]\,)^{-1} \qquad (6.5)$$

In the present case matrix $[T_1]$ was found to be fairly diagonal and matrix $[T]$ was highly diagonal as predicted earlier.

FIGURE 6.6

ALONG FRAME and ADJACENT FRAME SHEAR FORCE DISTRIBUTION

FOR TYPICAL INFLUENCE LOAD CASE


W
V
V
POSITIVE SHEAR
SIGN CONVENTION
5KN
36 KN
40KN
ALONG FRAME
SHEAR FORCE
100KN
FR 61 1/2
1KN
6KN
7KN
ADJACENT
FRAME
SHEAR FORCE
FR 61

a) ALONG FRAME

b) ADJACENT FRAME

The application of equation 6.1 is best illustrated with an example. In Figure 6.7 the panel is loaded in the middle at sub-panel 14 (see Figure 5.2) with 100 KN applied as uniform pressure. From the display of shear differences it can be seen that about 80% of the load actually shows up as a shear difference at the sub-panel of application. From the display of sub-panel loads calculated by equation 6.1, it is clear that for all practical purposes, all the applied load is showing up where it has been applied, with relatively little showing up elsewhere. It might be noted that a different type of loading (e.g. a point load) will produce different results as is illustrated in Section 7. This is due to the representation of loads by a cluster of uniform loads over distinct sub-panels (Figure 6.1). Finally, the display of approximate loads computed using a diagonal matrix [T] illustrates that the approximate shipboard procedure is expected to compute the load to within about 5%. Larger errors (notably at corresponding adjacent frame sub-panels) are indicated for surrounding sub-panels though these are expected to be less than 20%. Hence the ice loads are expected to be characterized quite well at their points of application on the instrumented panel.

Raw Strain Data at Gauge Locations (με)

+0.00	+5.77	+45.20	+5.77	+0.00
+0.00	+5.47	+47.85	+5.47	+0.00
+0.00	+3.08	+41.12	+3.08	+0.00
+0.00	-29.88	-196.22	-29.88	+0.00
+0.00	-32.41	-204.02	-32.41	+0.00
+0.00	+36.71	+229.43	+36.71	+0.00
+0.00	+40.69	+229.37	+40.69	+0.00

Shear Forces at Gauge Locations (N)

+0.00	+1028.61	+8057.75	+1028.61	+0.00
+0.00	+975.13	+8530.16	+975.13	+0.00
+0.00	+549.07	+7330.41	+549.07	+0.00
+0.00	-5326.67	-34979.88	-5326.67	+0.00
+0.00	-5777.69	-36370.38	-5777.69	+0.00
+0.00	+6544.24	+40900.19	+6544.24	+0.00
+0.00	+7253.75	+40889.49	+7253.75	+0.00

Shear Differences across Sub-panels (N)

+0.00	-53.48	+472.41	-53.48	+0.00
+0.00	-426.06	-1199.75	-426.06	+0.00
+0.00	-5875.74	-42310.29	-5875.74	+0.00
+0.00	-451.02	-1390.50	-451.02	+0.00
+0.00	+12321.93	+77270.57	+12321.93	+0.00
+0.00	+709.51	-10.70	+709.51	+0.00

Approximate Sub-panel Loads Compiled Using Diagonal [T], (N)

+0.00	-70.87	+626.22	-70.87	+0.00
+0.00	-645.83	-1818.96	-645.83	+0.00
-4.48	+20.03	-14.35	+20.03	-4.48
+0.00	-629.37	-1941.32	-629.37	+0.00
+0.00	+16816.68	+105528.78	+16816.68	+0.00
+0.00	+958.36	-14.45	+958.36	+0.00

Sub-Panel Loads Computed by Equation 6.1 (N)

+.02	-.09	+.58	-.09	+.02
+.04	-.06	+.46	-.06	+.04
-5.91	+20.50	-17.11	+20.50	-5.91
-.03	-1.00	-.72	-1.00	-.03
-.42	+2.67	+99999.86	+2.67	-.42
-.37	+2.27	-1.65	+2.27	-.37

FIGURE 6.7 : Predicted results of a 100 KN load applied as a Uniform Pressure over Sub-Panel 14 (The format of the above tables corresponds to the physical layout of the gauges and defined sub-panels. The location of the applied load is indicated by the box).

7. FULL SCALE PHYSICAL CALIBRATION

From the finite element analysis it was determined that a sub-panel pressure load totalling 100 KN (i.e. a hull pressure of about 1 MPa) could lead to inelastic bending of the adjoining frame (based on a factor of safety of 2) Hence it was decided to restrict calibration loads to below 50 KN. In addition the frames were to be loaded through the vertex of the angle (i.e. shear centre) to avoid twisting.

Six calibration points were selected, 2 each on frames 61½, 60½ and 59½ as shown schematically in Figure 7.1. A horizontal header bar was mounted on the centre-line bulkhead in the starboard dry tank and padeyes attached in the planes of the above mentioned frames of interest as illustrated in Figure 7.2. Padeyes were also welded to the webs of the frames of interest at the calibration points as shown in Figure 7.3. The header bar was secured by installing vertical gussets in the planes of the odd frames (frames 61, 60 and 59) to hold it in place as shown in Figures 7.3 and 7.4. With this arrangement the calibration loads could be applied through co-planar padeyes.

The six calibration points were loaded in the planes of their respective frames by 3 different loads (1 ton = 8.896 KN, 3 tons = 26.69 KN and 4.5 tons = 40.03 KN). The 18 individual calibration readings are presented in Appendix F. Overall the results of this exercise indicated that the shear difference across loaded sub-panels was close to linear and that each of the calibrated frames exhibited roughly the same loaded sub-panel shear difference for a given load. Hence the assumptions of linearity and similarity of frames used in the finite element analysis appear to be justified. The results of the 1 ton calibration loading of sub-panel 26 are indicated in matrix form in Figure 7.5. The format of these matrices corresponds to the physical layout of the gauges and defined sub-panels as viewed from inside the ship (see Figure 5.2). The location of the load is indicated with a box and it can be seen that the most significant shear difference occurs there. The results of similarly loading the same sub-panel in the analytical model with 50 KN is shown in Figure 7.6. Note that almost all the load is predicted to show up as a shear difference across the loaded sub-panel.

FIGURE 7.1

LOCATION OF CALIBRATION POINTS

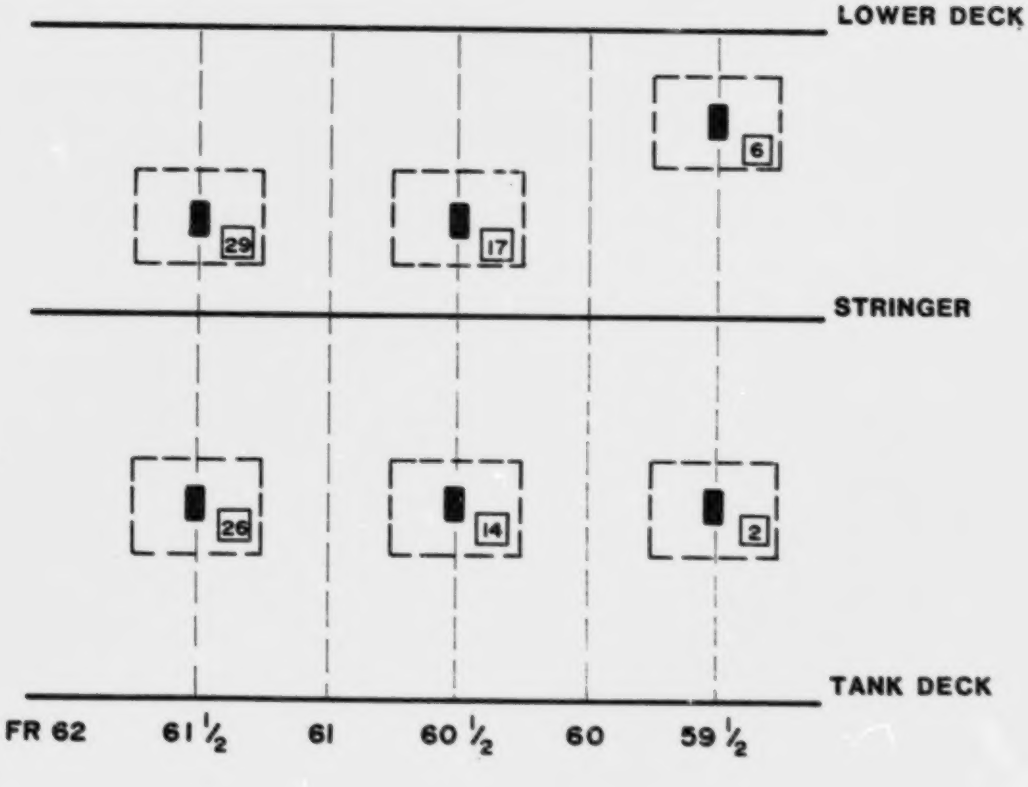
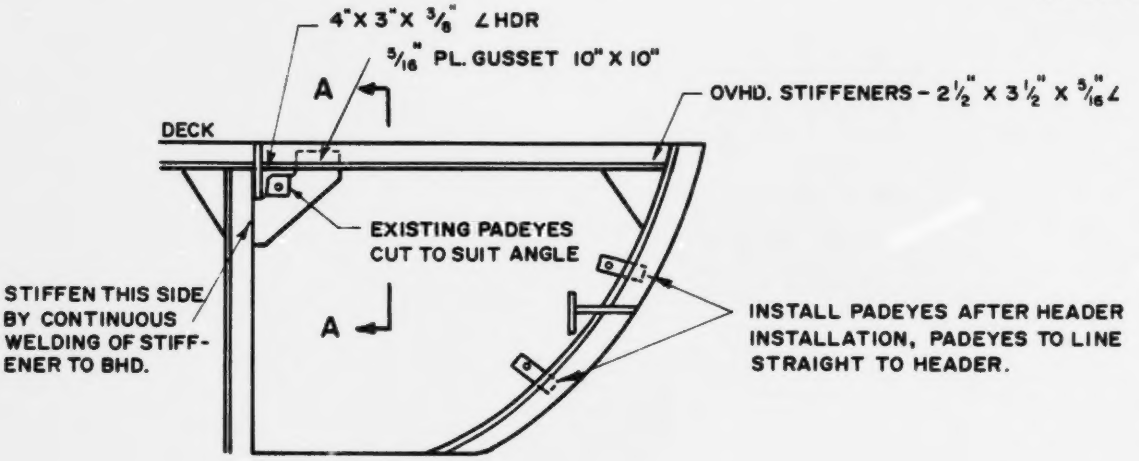
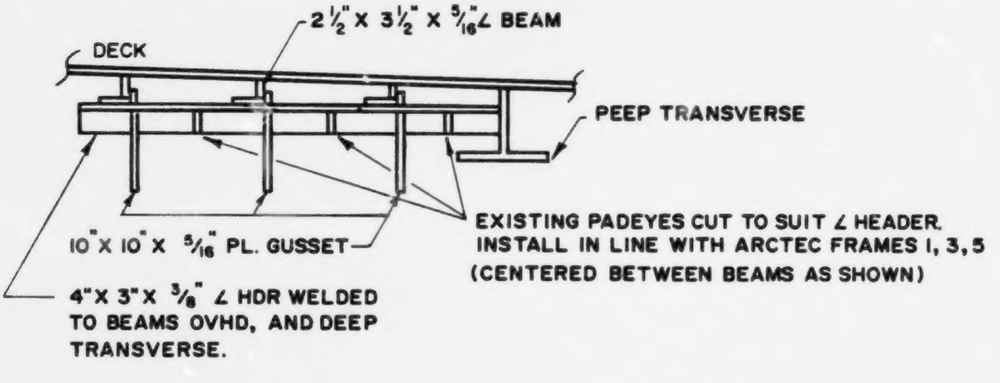

LOWER DECK
6
29
17
STRINGER
26
14
2
TANK DECK
FR 62
61 ½
61
60 ½
60
59 ½

FIGURE 7.2
SKETCH OF CAPE BRIER DRY TANK GAUGE CALIBRATION

PADEYE INSTALLATION

(N.T.S.)


4"X 3"X 3/8" ∠HDR
5/16" PL. GUSSET 10"X 10"
A
OVHD. STIFFENERS - 2½" X 3½" X 5/16"∠
DECK
EXISTING PADEYES
CUT TO SUIT ANGLE
STIFFEN THIS SIDE
BY CONTINUOUS
WELDING OF STIFF-
ENER TO BHD.
A
INSTALL PADEYES AFTER HEADER
INSTALLATION, PADEYES TO LINE
STRAIGHT TO HEADER.


2½" X 3½" X 5/16"∠ BEAM
DECK
PEEP TRANSVERSE
EXISTING PADEYES CUT TO SUIT ∠ HEADER.
INSTALL IN LINE WITH ARCTEC FRAMES 1, 3, 5
(CENTERED BETWEEN BEAMS AS SHOWN)
10"X 10"X 5/16" PL. GUSSET
4"X 3"X 3/8" ∠ HDR WELDED
TO BEAMS OVHD, AND DEEP
TRANSVERSE.

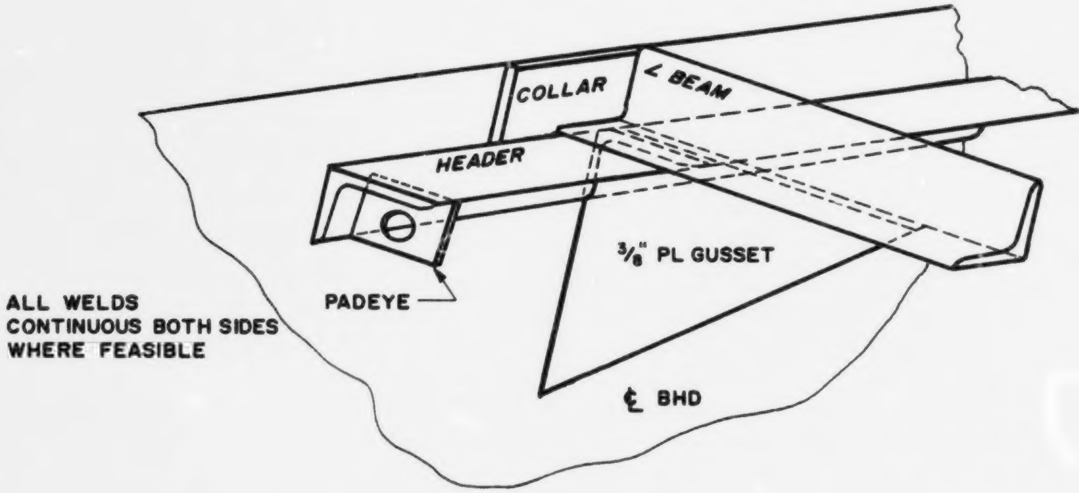
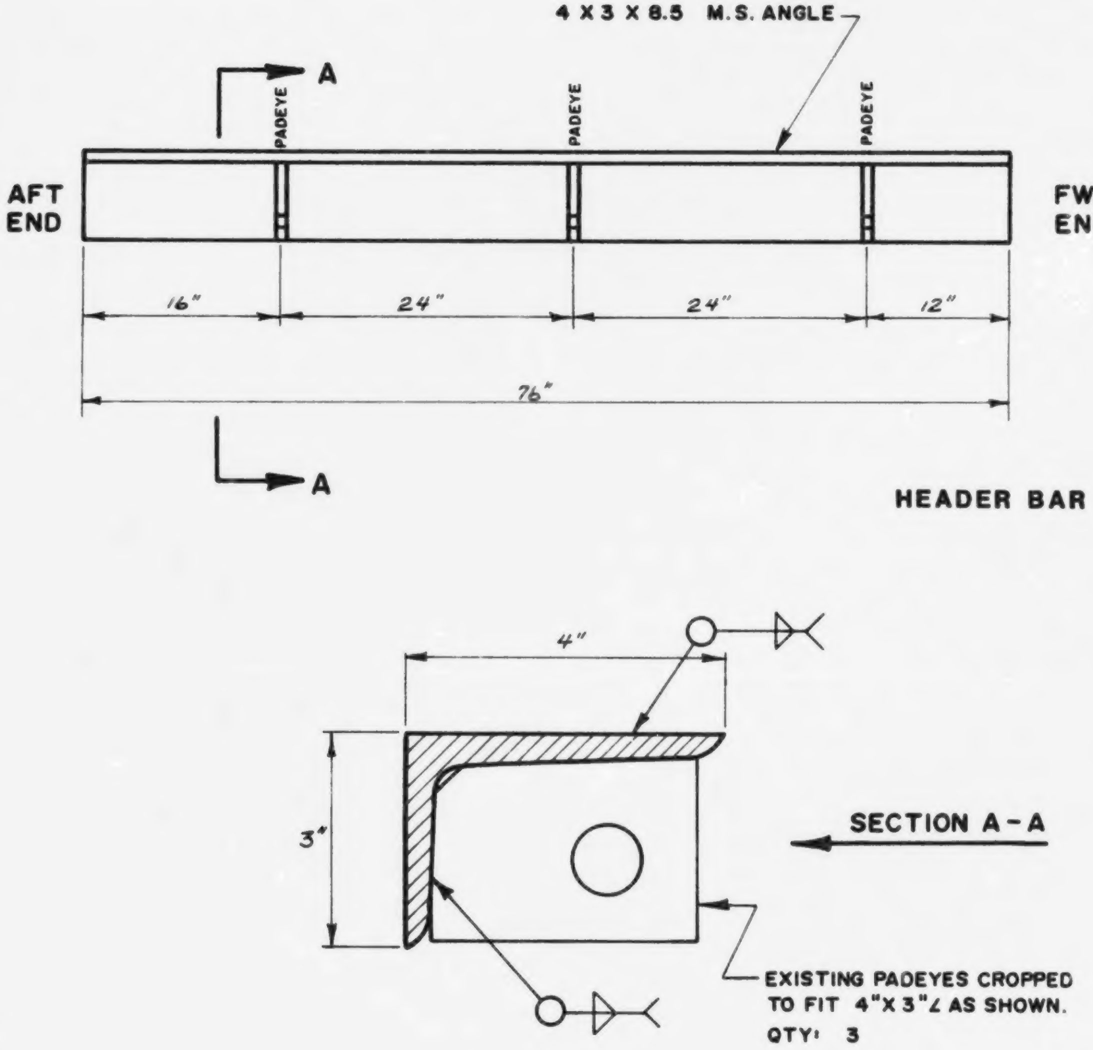

COLLAR
∠ BEAM
HEADER
3/8" PL GUSSET
ALL WELDS
CONTINUOUS BOTH SIDES
WHERE FEASIBLE
PADEYE
℄ BHD

FIGURE 7.3

FABRICATION SKETCHES

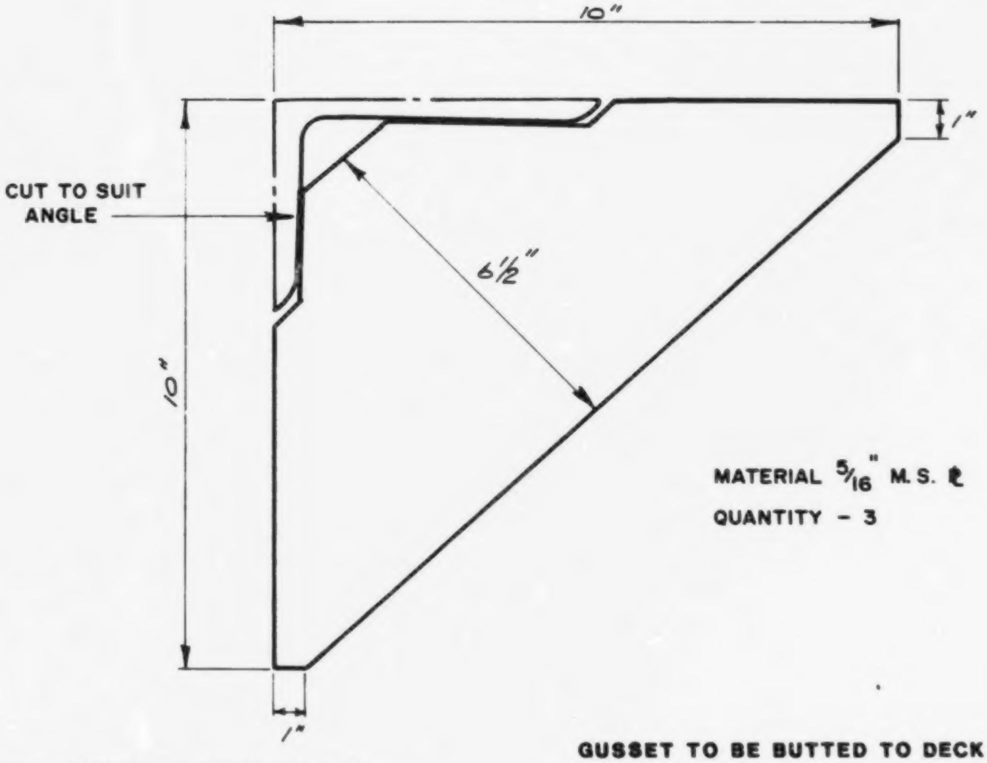
CAPE BRIER CALIBRATION HEADER


4 X 3 X 8.5 M.S. ANGLE
A
PADEYE
PADEYE
PADEYE
AFT END
FWD END
16"
24"
24"
12"
76"
A
HEADER BAR
4"
3"
SECTION A-A
EXISTING PADEYES CROPPED TO FIT 4"X 3"∠ AS SHOWN.
QTY: 3

AT INSTALLATION, ADJUST POSITION SO THAT PADEYES LIE IN THE PLANES OF STRAIN-GAUGED FRAMES #1, 3, & 5. FWD END MAY BE CROPPED IF N'C'Y.

FIGURE 7.4

HEADER BAR GUSSET


10"
1"
CUT TO SUIT ANGLE
6½"
10"
1"

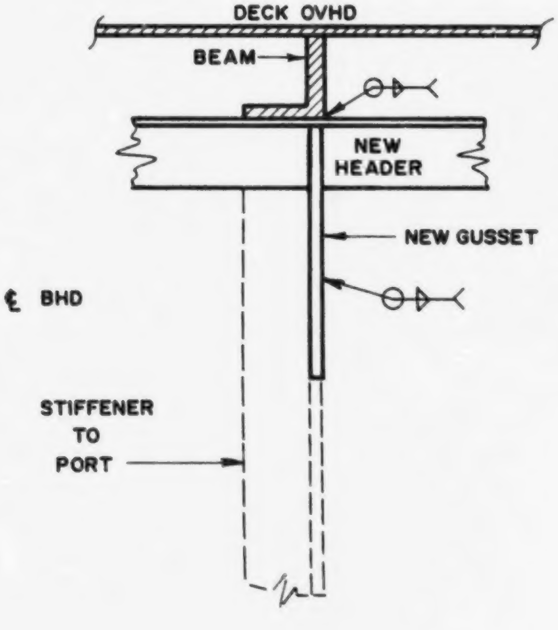
MATERIAL 5/16" M. S. ℄

QUANTITY - 3

NOTE: HEIGHT OF GUSSETS MAY HAVE TO BE SHORTENED TO FIT OVER TOP OF BHD.-MOUNTED TANK.

(CAN BE CLIPPED TO SUIT IN FIELD)

GUSSET TO BE BUTTED TO DECK BEAM AND ALIGNED WITH BHD STIFFENER ON OPP SIDE OF ℄ OF BHD.


DECK OVHD
BEAM
NEW HEADER
NEW GUSSET
℄ BHD
STIFFENER TO PORT

Raw Strain Data at Gauge Locations ($\mu\varepsilon$)

-.44	-.52	+4.51	-.39	+8.11
-.44	+.34	+3.23	-.39	-.90
-.18	+.72	+1.95	-.59	-1.92
+8.81	+1.38	-2.54	+.05	-1.92
$\boxed{+12.23}$	+1.15	-2.10	+.68	-1.66
$\boxed{-12.45}$	+.04	-1.71	+.44	-1.28
-9.42	-1.07	-2.12	+.19	-1.51

Shear Forces at Gauge Locations (N)

-78.24	-92.11	+803.69	-69.35	+1445.73
-78.24	+59.97	+575.36	-69.35	-161.28
-32.04	+128.72	+347.03	-105.70	-341.43
+1569.85	+245.41	-452.61	+8.11	-342.23
$\boxed{+2179.76}$	+204.69	-373.66	+121.93	-296.20
$\boxed{-2219.13}$	+7.17	-304.54	+77.86	-228.43
-1678.68	-190.34	-377.67	+33.80	--268.67

Shear Differences across Sub-Panels (N)

+0.00	+152.08	-228.33	+0.00	-1607.00
+46.20	+68.75	-228.33	-36.35	-180.15
+1601.89	+116.70	-799.64	+113.81	-.80
+609.91	-40.73	+78.95	+113.81	+46.03
$\boxed{-4398.89}$	-197.51	+69.12	-44.06	+67.76
+540.46	-197.51	-73.13	-44.06	-40.24

Approximate Sub-Panel Loads Computed Using Diagonal [T] (N)

+0.00	+201.52	-302.67	+0.00	-2090.40
+69.01	+104.21	-346.17	-55.11	-269.09
-11425.98	+14796.14	-43876.75	+19779.38	-36375.69
+832.09	-56.83	+110.23	+158.82	+62.80
$\boxed{-5846.44}$	-269.56	+94.40	-60.14	+90.06
+714.35	-266.79	-98.83	-59.52	-53.18

Sub-Panel Loads Computed by Equation 6.1 (N)

+19.55	+188.93	-307.55	+265.72	-2056.87
+25.44	+52.82	-247.55	-6.95	-271.58
-12723.97	+18908.32	-46632.31	+25658.25	-38055.85
+499.07	+442.70	-432.22	+1016.97	-233.22
$\boxed{-5837.88}$	+733.58	-182.44	+29.64	-33.49
+709.17	-233.89	-123.61	+49.38	-89.30

FIGURE 7.5: Measured Results of the 1 ton Calibration Loading of Sub-Panel 26 (The format of the above table corresponds to the physical layout of the gauges and defined sub-panels. The location of the applied load is indicated by the box).

Raw Strain Data at Gauge Locations ($\mu\varepsilon$)

+76.63	+.84	+0.00	+0.00	+0.00
+82.12	+1.50	+0.00	+0.00	+0.00
+87.51	-.76	+0.00	+0.00	+0.00
-356.10	-21.24	+0.00	+0.00	+0.00
-406.90	-18.00	+0.00	+0.00	+0.00
+453.40	+13.70	+0.00	+0.00	+0.00
+403.00	+17.32	+0.00	+0.00	+0.00

Shear Forces at Gauge Locations (N)

+4449.75	+48.78	+0.00	+0.00	+0.00
+4768.54	+87.10	+0.00	+0.00	+0.00
+5081.53	-44.13	+0.00	+0.00	+0.00
-20678.01	-1233.36	+0.00	+0.00	+0.00
-23627.86	-1045.22	+0.00	+0.00	+0.00
+26328.02	+795.53	+0.00	+0.00	+0.00
+23401.00	+1005.74	+0.00	+0.00	+0.00

Shear Differences across Sub-Panels (N)

+318.79	+38.32	+0.00	+0.00	+0.00
+312.99	-131.23	+0.00	+0.00	+0.00
-25759.54	-1189.23	+0.00	+0.00	+0.00
-2949.85	+188.14	+0.00	+0.00	+0.00
+49955.88	+1840.75	+0.00	+0.00	+0.00
-2926.63	+210.21	+0.00	+0.00	+0.00

Approximate Sub-Panel Loads Computed Using Diagonal [T] (N)

+414.69	+50.79	+0.00	+0.00	+0.00
+467.51	-198.93	+0.00	+0.00	+0.00
+3597.32	-15834.61	+5737.91	-2018.45	+619.67
-4024.44	+262.54	+0.00	+0.00	+0.00
-66394.99	+2512.22	+0.00	+0.00	+0.00
-3868.25	+283.93	+0.00	+0.00	+0.00

Sub-Panel Loads Computed by Equation 6.1 (N)

+7.45	+177.85	-51.67	+13.96	-3.63
+1424.39	-24.40	-56.54	+22.52	-6.65
+4798.20	-16563.33	+7048.26	-2557.93	+799.04
-2797.09	+826.39	+34.35	-76.61	+33.76
+65922.86	-8355.83	+1373.53	-231.19	+39.42
-3718.71	+161.76	+78.24	-32.21	+8.83

FIGURE 7.6: Predicted Results of a 50 KN Calibrated Loading of Sub-Panel 26 (The format of the above tables corresponds to the physical layout of the gauges and defined sub-panels). The location of the applied load is indicated by the box.

For comparison, the results of loading the same sub-panel with 100 KN applied as a uniform hull pressure (used in the development of equation 6.1) are indicated in Figure 7.7. In this case, only about 70% of the applied load is predicted to show up as a shear difference across the loaded sub-panel. However, the load prediction indicates essentially all the applied load to be at the loaded sub-panel, which is what is required of a theoretical model predicting ice pressures. This difference in the type of loading accounts for the apparently greater than applied sub-panel load predicted in Figure 7.6.

From the display of shear forces in these physical calibration cases it was observed that a positive measurement corresponded to negative in the analytical model. It was also observed from the cross stringer shear differences that the relatively large stringer reaction predicted by the analytical model did not materialize. Hence the stringer reaction used in Equation 6.1 was over-estimated, resulting in relatively high "apparent" loads at sub-panels traversing the stringer.

It is useful to compare the (derived) measured loads on the loaded sub-panels with the theoretically expected values. This is done for sub-panel 29 in Figure 7.8 and for sub-panel 26 in Figure 7.9 by plotting each of these quantities against the applied calibration loads. Note that the measured sub-panel loads are approximately linear with the applied load as was indicated previously. A further observation is that the theoretically predicted sub-panel loads (at the location of the load) are approximately double the measured values. In light of this and the apparent sign discrepancy between measured and theoretical values of shear force seen in all the calibration results, the "factor" in equation 5.2 was halved and the sign changed from positive to negative.

A final observation is that some of the derived sub-panel loads can show up as negative values (i.e. negative ice pressure loading). For the purpose of the subsequent data analysis these are ignored and only the positive values of load are retained.

Raw Strain Data at Gauge Locations ($\mu\varepsilon$)

+45.20	+5.77	+0.00	+0.00	+0.00
+47.85	+5.47	+0.00	+0.00	+0.00
+41.12	+3.08	+0.00	+0.00	+0.00
-196.22	-29.88	+0.00	+0.00	+0.00
-204.02	-32.41	+0.00	+0.00	+0.00
+229.43	+36.71	+0.00	+0.00	+0.00
+229.37	+40.69	+0.00	+0.00	+0.00

Shear Forces at Gauge Locations (N)

+8057.75	+1028.61	+0.00	+0.00	+0.00
+8530.16	+975.13	+0.00	+0.00	+0.00
+7330.41	+549.07	+0.00	+0.00	+0.00
-34979.88	-5326.67	+0.00	+0.00	+0.00
-36370.38	-5777.69	+0.00	+0.00	+0.00
+40900.19	+6544.24	+0.00	+0.00	+0.00
+40889.49	+7253.75	+0.00	+0.00	+0.00

Shear Differences across Sub-Panels (N)

+472.41	-53.48	+0.00	+0.00	+0.00
-1199.75	-426.06	+0.00	+0.00	+0.00
-42310.29	-5875.74	+0.00	+0.00	+0.00
-1390.50	-451.02	+0.00	+0.00	+0.00
+77270.57	+12321.93	+0.00	+0.00	+0.00
-10.70	+709.51	+0.00	+0.00	+0.00

Approximate Sub-Panel Loads Computed Using Diagonal [T] (N)

+614.52	-70.87	+0.00	+0.00	+0.00
-1792.07	-645.83	+0.00	+0.00	+0.00
-9.36	+18.55	-4.50	+1.48	-.44
-1897.03	-629.37	+0.00	+0.00	+0.00
+102698.19	+16816.68	+0.00	+0.00	+0.00
-14.14	+958.36	+0.00	+0.00	+0.00

Sub-Panel Loads Computed by Equation 6.1 (N)

+.56	-.08	+.02	-.01	+0.00
+.42	-.05	+.04	-.01	+0.00
-10.62	+18.57	- 5.91	+1.92	-.58
-.66	-1.06	-.03	+.07	-.03
+100000.29	+2.59	-.42	+.07	-.01
-1.27	+2.20	-.37	+.07	-.01

FIGURE 7.7: Predicted Results of a 100 KN Load Applied as a Uniform Pressure Over Sub-Panel 26 (The format of the above tables corresponds to the physical layout of the gauges and defined sub-panels. The location of the applied load is indicated by the box).

FIGURE 7.8 COMPARISON of MEASURED and THEORETICAL SUB PANEL CALIBRATION LOADS AT SUB PANEL #29

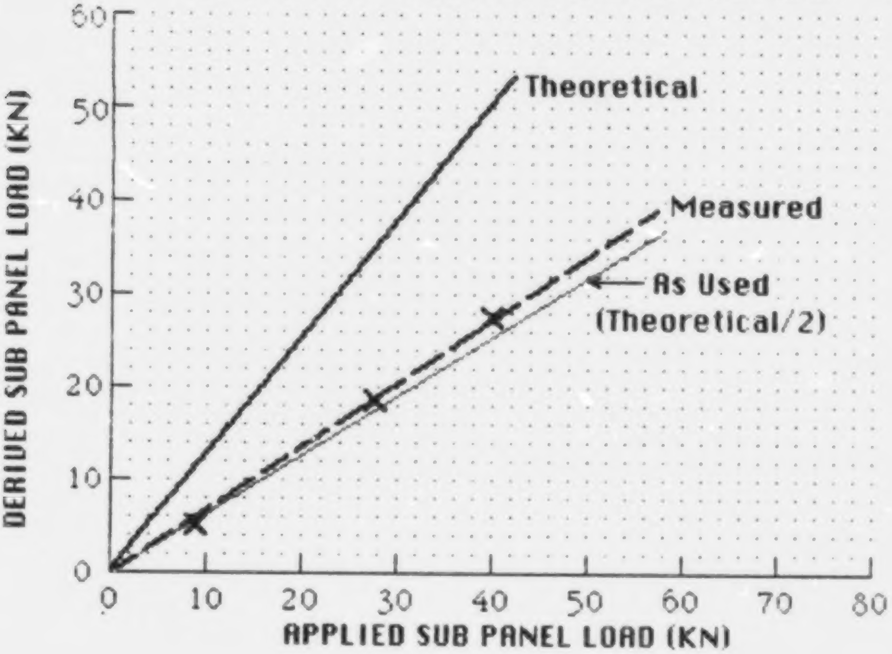
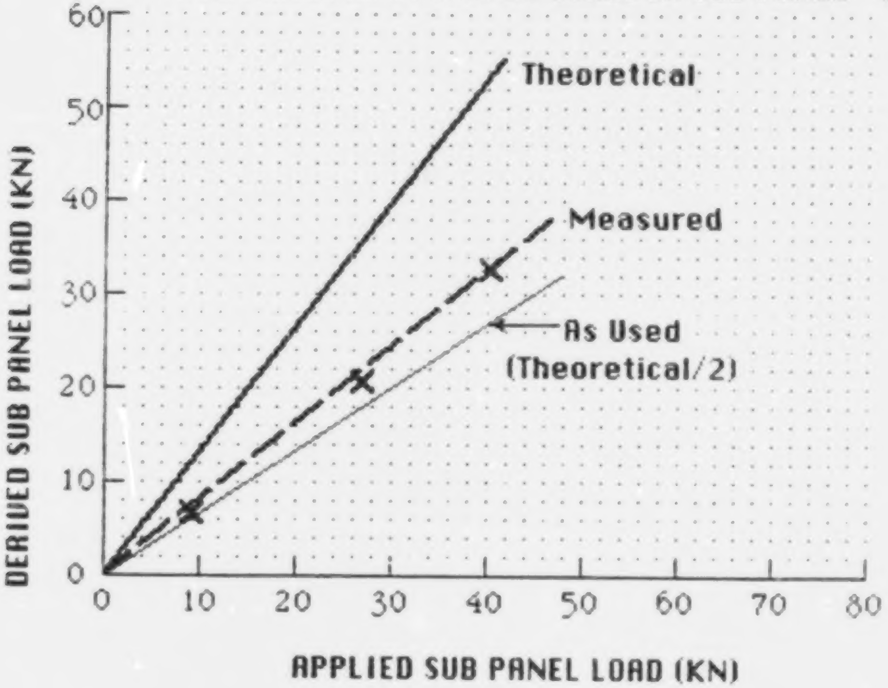


FIGURE 7.9 COMPARISON of MEASURED and THEORETICAL SUB PANEL CALIBRATION LOADS AT SUB PANEL #26



8. ICE AND ENVIRONMENTAL DATA

8.1 Approach and Methodology

As noted in Section 3, the ice environment in the project area varies annually, seasonally and on short time scales of days or hours. Long-term climatic statistics such as those presented in Section 3 are therefore not necessarily representative of actual test conditions.

Actual data were collected by the test engineer on an opportunity basis during the test. The parameters recorded are listed in Table 8.1 and environmental log sheets with the field data are included in Appendix B. In addition, numerous photographs of surrounding ice were taken from the bridge deck. Ice floe size was not recorded in the field, and instead was estimated from the photographs.

Data were recorded in the field on an hourly basis, or when significant changes in ice or sea conditions occurred. More detailed observations on the mechanics of ice impact with the test panel were made during a short period of dedicated testing on March 20.

TABLE 8.1

ENVIRONMENTAL DATA COLLECTED ON MV CAPE BRIER

Navigation Data	
Time	
Ship Position	latitude/longitude
Ship Heading	
Ship Speed	knots
Meteorological Data	
Air temperature	°C
Precipitation	Presence of rain, snow or fog
Visibility	Estimate of visibility from bridge, n. miles
Wind Speed	knots
Wind Direction	
Oceanographic Data	
Wave Height	Significant height in metres
Wave Direction	
Ice Data	
Ice Type and Concentration -	Total = new ice + grey ice + grey-white ice + first year ice + multi-year ice, in tenths
Average Thickness -	Estimated from upturned floe edges, in metres
Average Floe Diameter -	Estimated from photographs, in metres
Number of Icebergs -	From radar or visual count to limits of visibility
Size of Icebergs -	Estimated onboard or measured from photographs

8.2 Environmental Conditions Encountered

An overview of average ice type and concentration in the project region is provided by Atmospheric Environment Service (AES) Current Ice Condition charts, shown in Figure 8.1 through 8.4. These are derived from satellite and aircraft reconnaissance and ship and shore reports. A key to the "egg" code used in the charts, is given in Appendix C. The daily ship's track has been superimposed on the charts.

The charts provide an average or overview of ice conditions which is different from the hourly observations in the ship log. This is due to the spatial averaging process inherent in mapping, and to short-term changes in conditions which are not resolved by the mapping frequency. The hourly record of ice concentration, mean floe size, mean floe thickness and vessel speed is summarized in Figures 8.5 through 8.11. A daily record of test conditions follow.

March 18

The CAPE BRIER entered pack ice on March 18, proceeding north through 9 to 10/10ths cover of mainly thin, first-year ice.

March 19

She continued north on the 19th, proceeding through variable concentrations and thickness of sea ice, including a trace of multi-year. Weather was good through most of the day, with air temperatures 0°C, water calm and wind 1 to 3 knots from the northwest. Light flurries and slightly higher winds occurred in the late afternoon as the ice pack edge was approached.

March 20

Course on the 20th was generally north-north east, parallel with the pack edge. Heavier ice was encountered, with higher average concentration and more thick ice than on the 19th. Weather conditions were good. Detailed observations of ice impact on the load panel were made at 10:36, 11:00, 13:10 and 15:20. These are given in Appendix B.

FIGURE 8.1

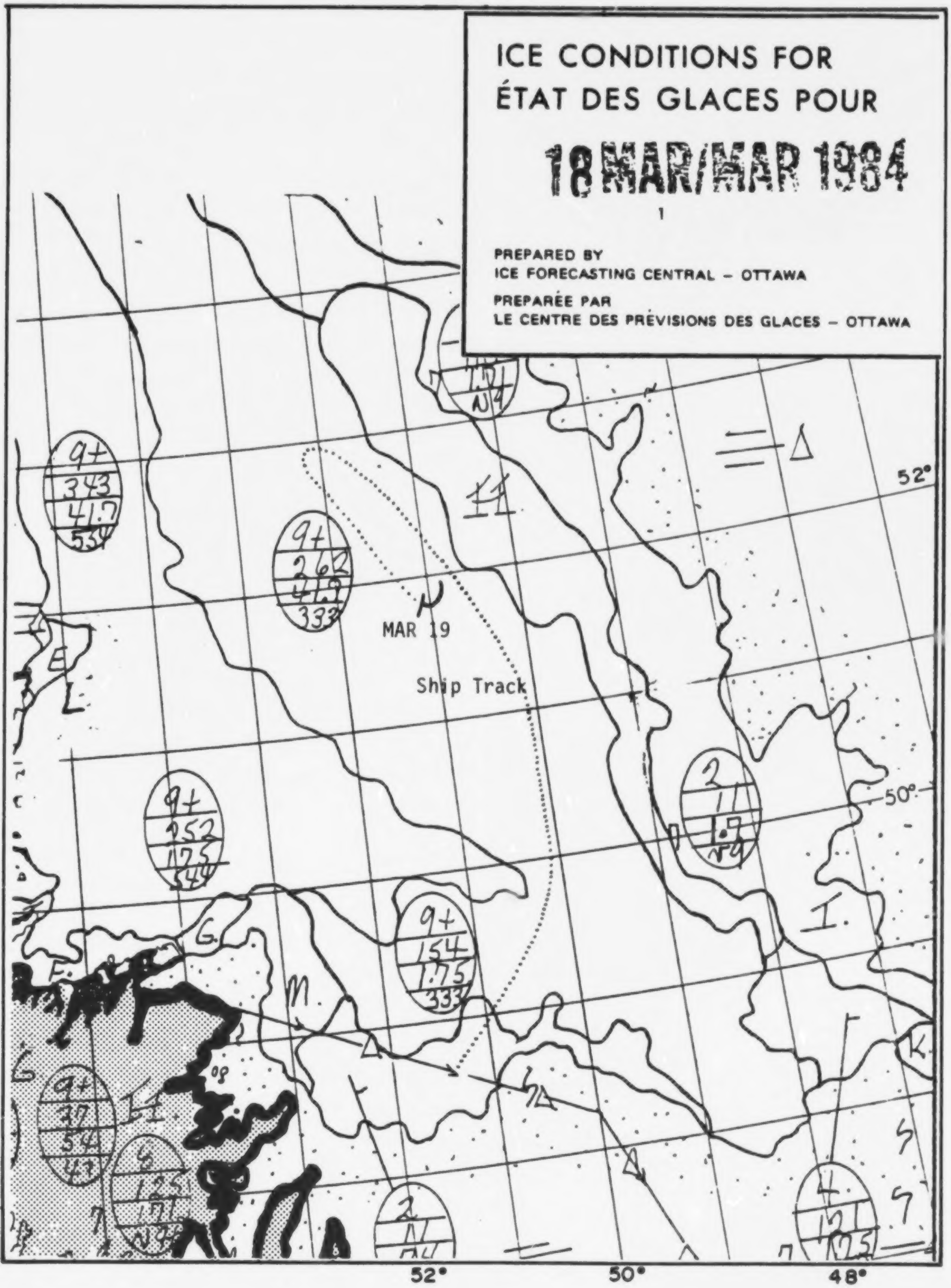
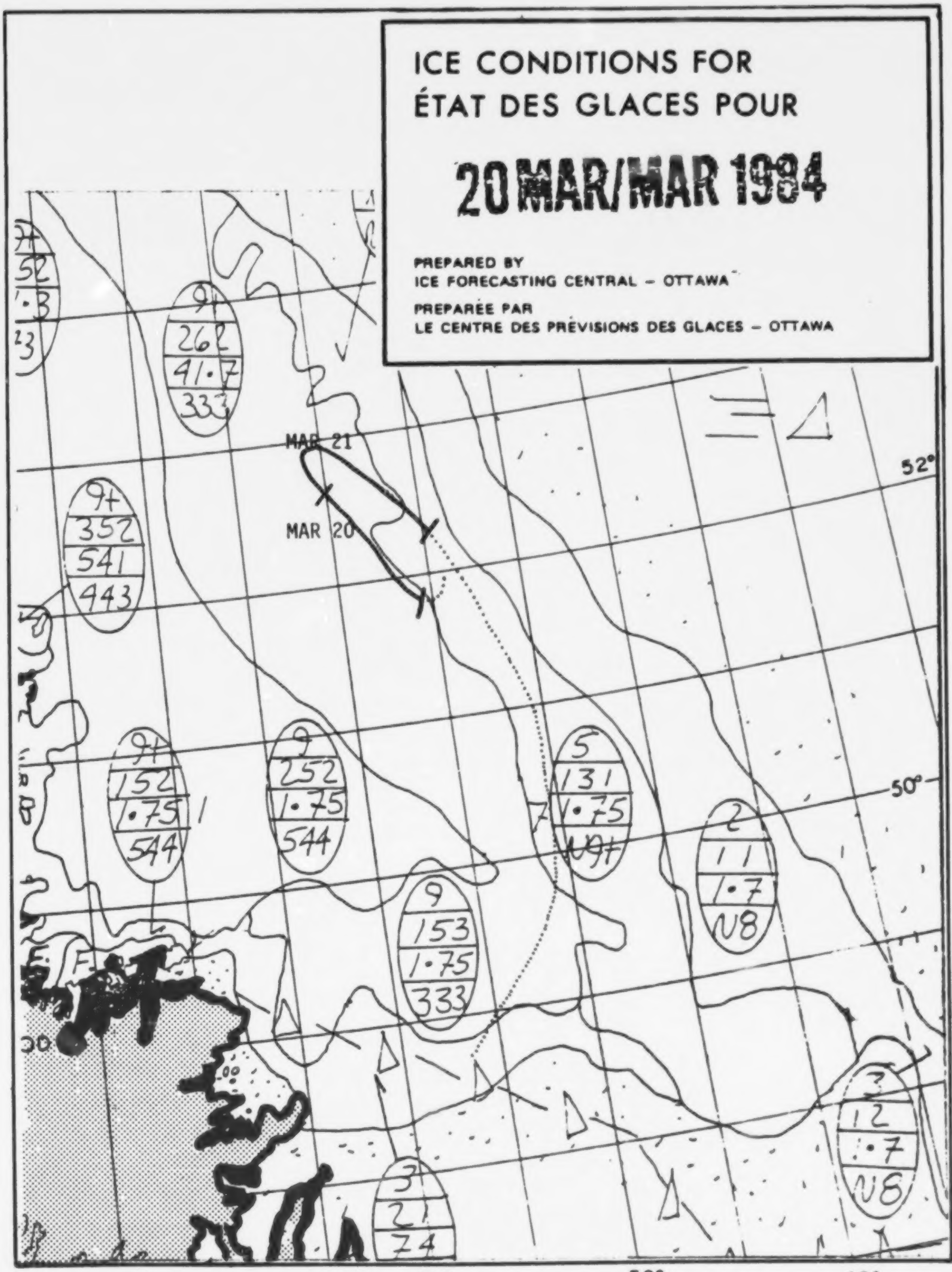

ICE CONDITIONS FOR
ÉTAT DES GLACES POUR
18 MAR/MAR 1984
1
PREPARED BY
ICE FORECASTING CENTRAL – OTTAWA
PREPARÉE PAR
LE CENTRE DES PRÉVISIONS DES GLACES – OTTAWA
MAR 19
Ship Track
52°
50°
52°
50°
48°
9+
343
41.7
534
9+
262
41.9
333
9+
252
175
544
9+
154
1.75
333
2
11
1.7
N4
E
L
G
F
M
K
I
S

FIGURE 8.2


ICE CONDITIONS FOR
ÉTAT DES GLACES POUR

20 MAR/MAR 1984

PREPARED BY
ICE FORECASTING CENTRAL – OTTAWA
PREPAREE PAR
LE CENTRE DES PRÉVISIONS DES GLACES – OTTAWA

MAR 21
MAR 20
52°
50°
52°
50°
48°
9+ 52 1·3 23
9+ 262 41·7 333
9+ 352 541 443
9+ 152 1·75 544
9 252 1·75 544
5 131 1·75 N9+
2 11 1·7 N8
9 153 1·75 333
3 12 1·7 N8
3 21 74

FIGURE 8.3

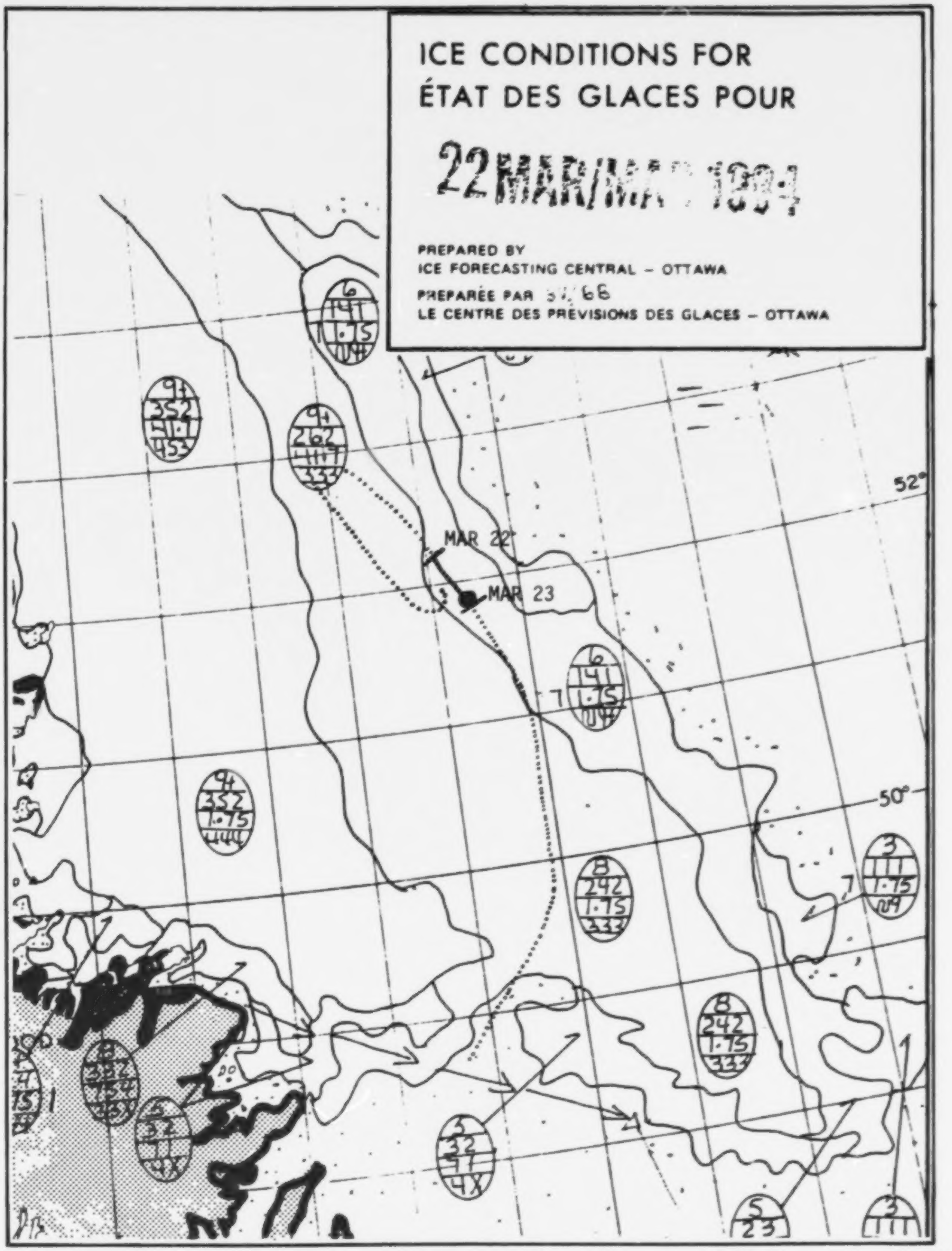

ICE CONDITIONS FOR
ÉTAT DES GLACES POUR
22 MAR/MAR 1984
PREPARED BY
ICE FORECASTING CENTRAL – OTTAWA
PRÉPARÉE PAR 57/66
LE CENTRE DES PREVISIONS DES GLACES – OTTAWA
MAR 22
MAR 23
52°
50°
52°
50°
48°

FIGURE 8.4

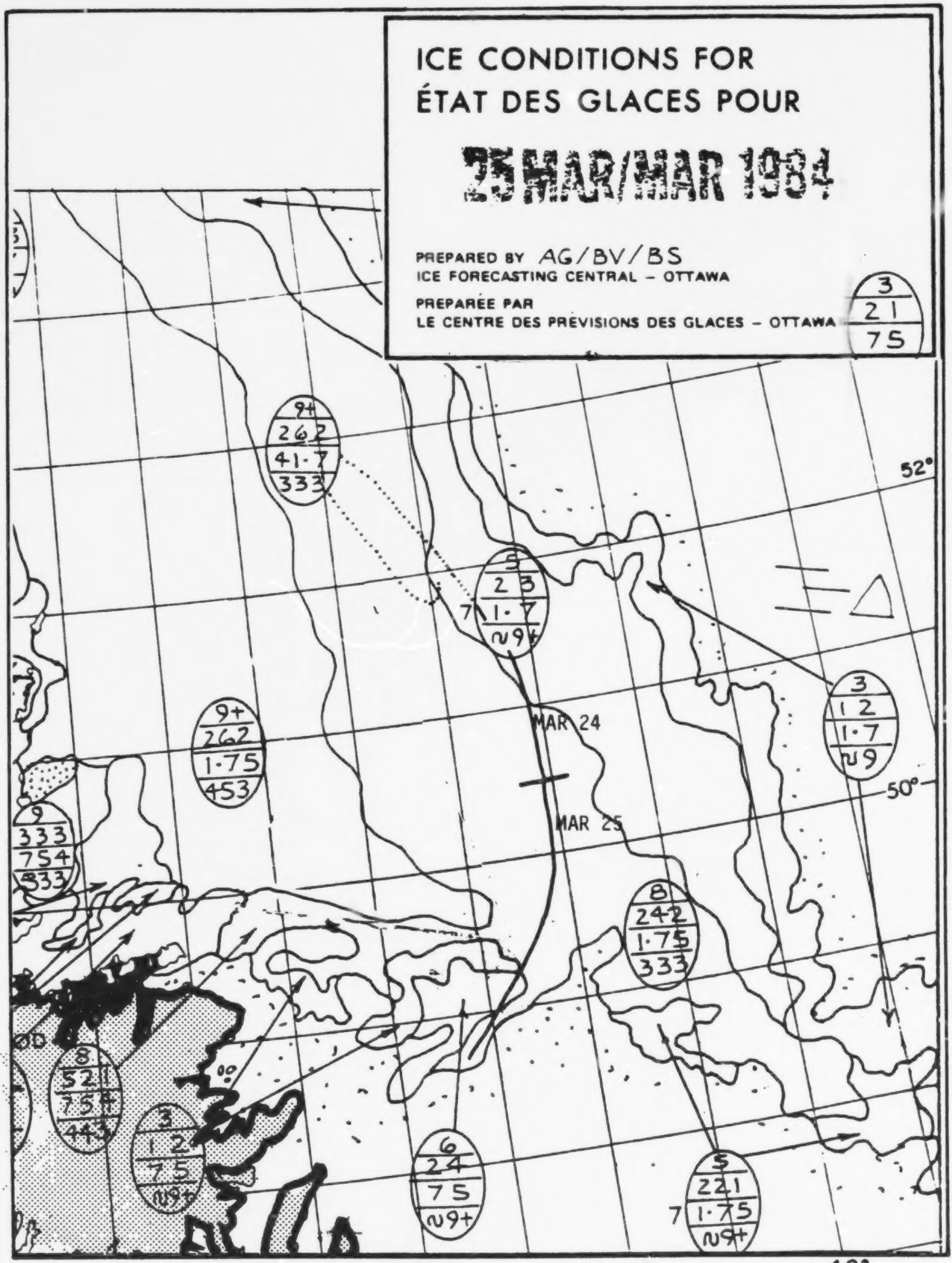

ICE CONDITIONS FOR
ÉTAT DES GLACES POUR
25 MAR/MAR 1984
PREPARED BY AG/BV/BS
ICE FORECASTING CENTRAL – OTTAWA
PREPAREE PAR
LE CENTRE DES PREVISIONS DES GLACES – OTTAWA
3 21 75
9+ 262 41·7 333
5 23 7 1·7 ~9+
52°
9+ 262 1·75 453
3 12 1·7 ~9
MAR 24
MAR 25
50°
9 333 754 333
8 242 1·75 333
8 521 75 443
3 12 75 ~9+
6 24 75 ~9+
5 221 7 1·75 ~9+
52°
50°
48°

Figure 8.5 SHIP'S LOG DATA
March 19

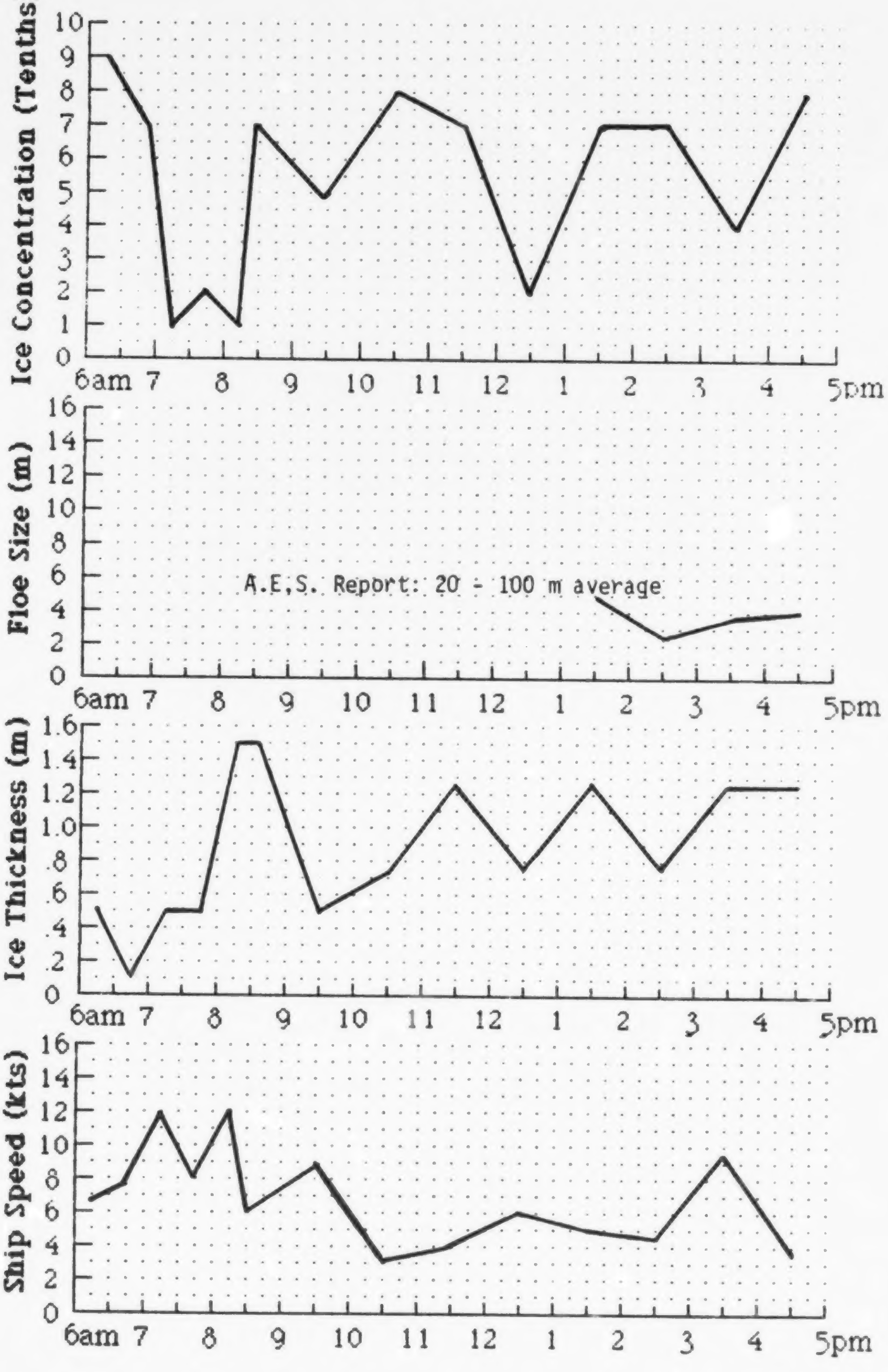


Figure 8.6 SHIP'S LOG DATA
March 20

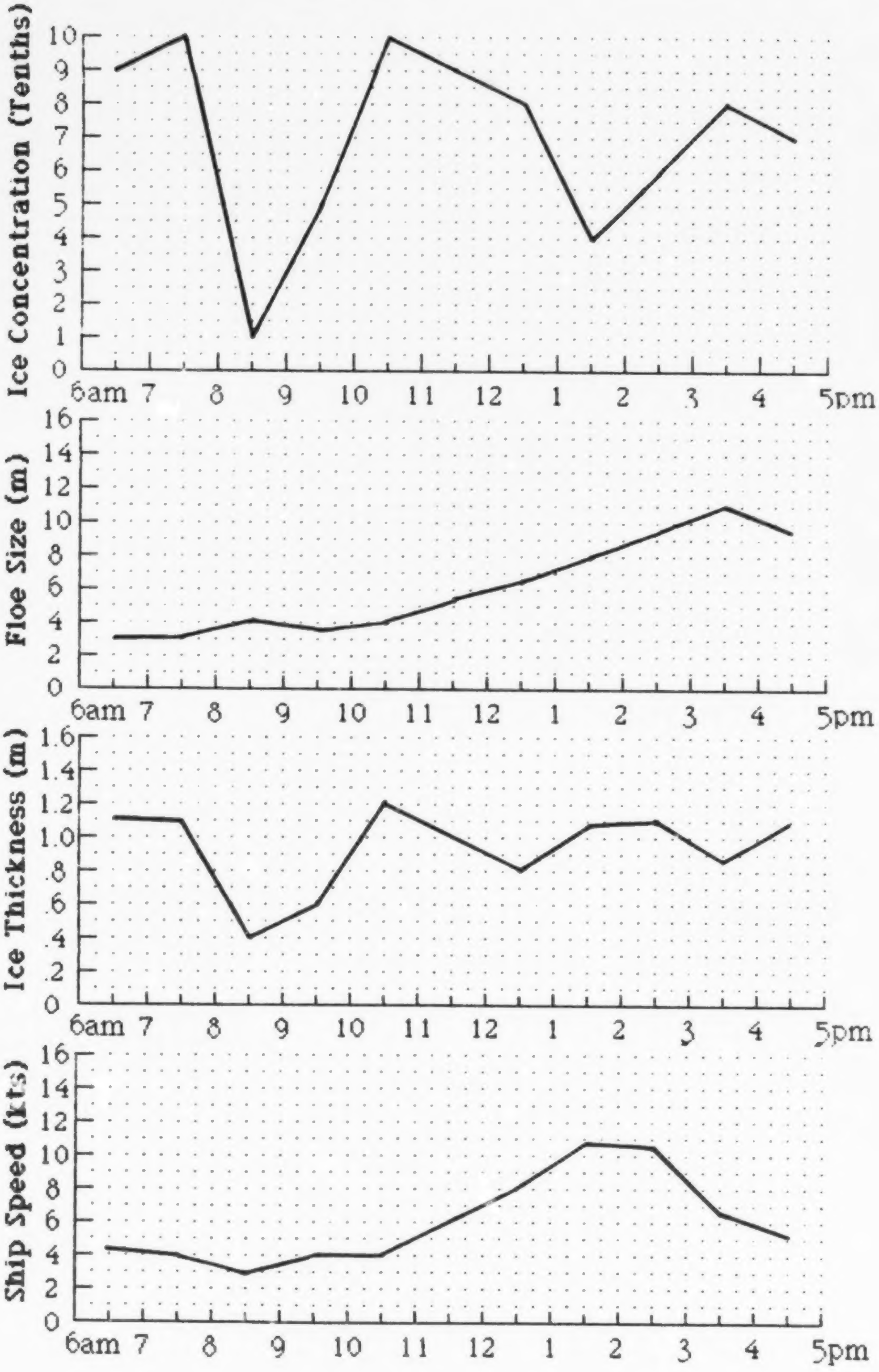


Figure 8.7 SHIP'S LOG DATA
March 21

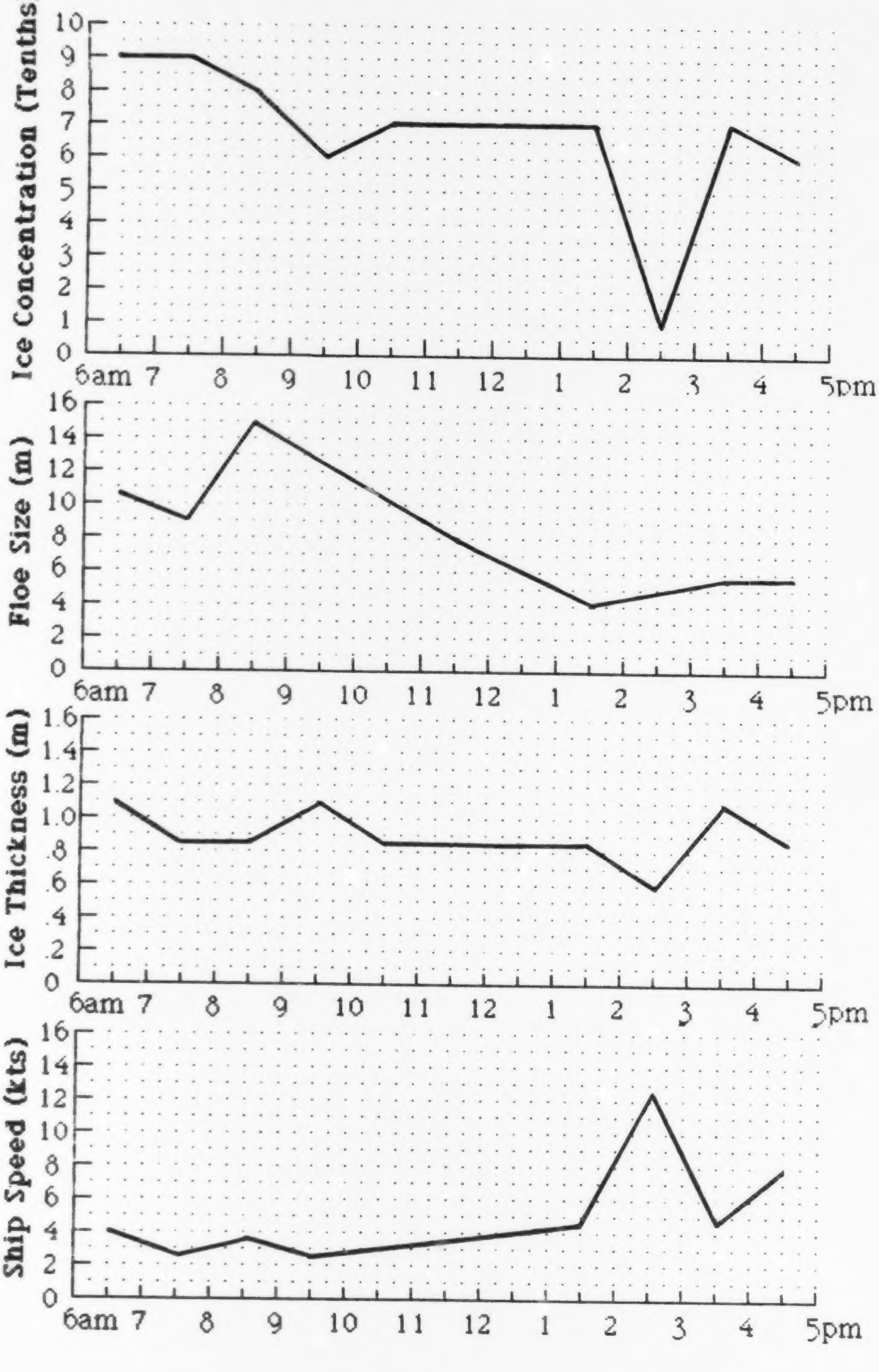
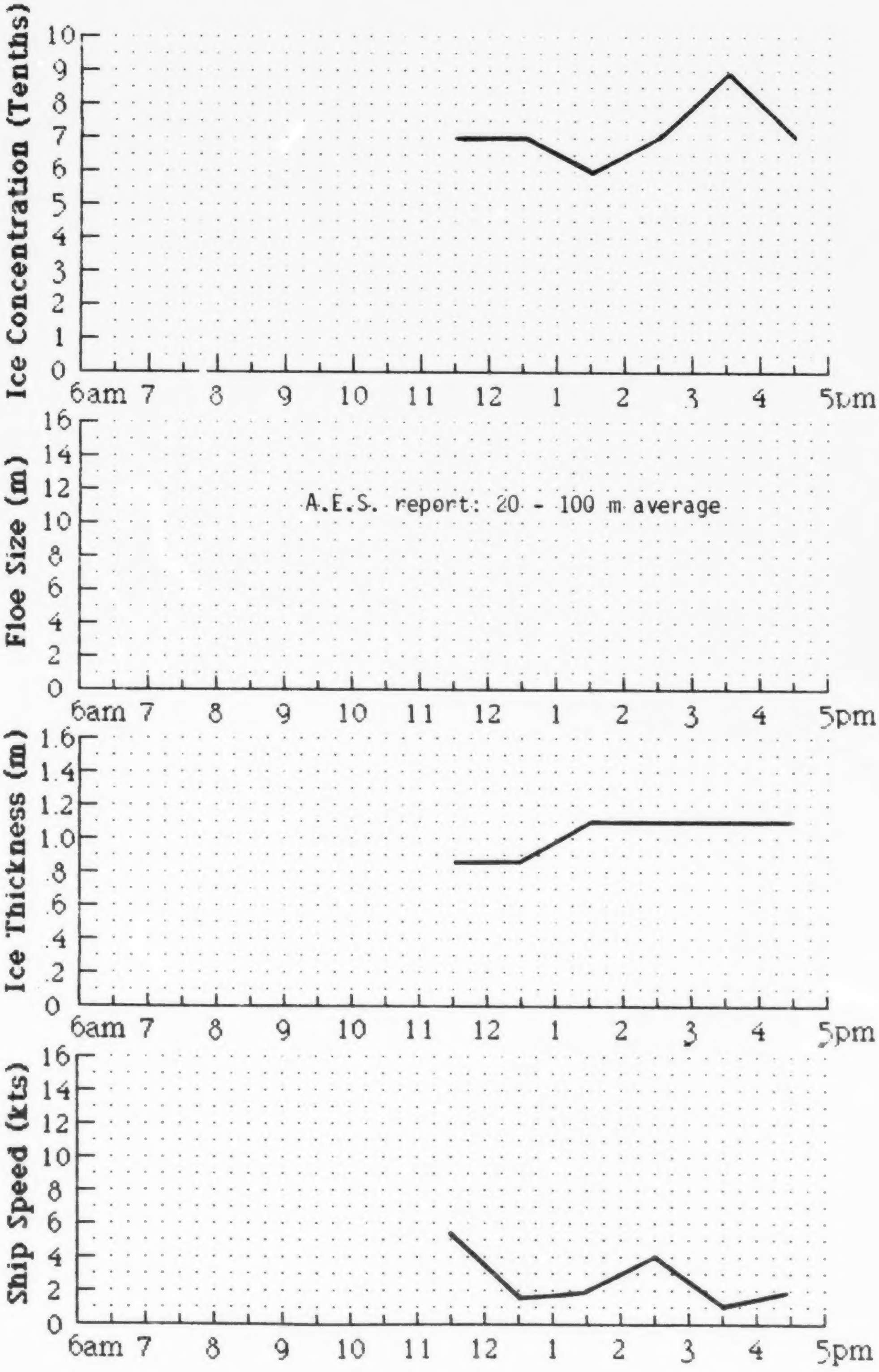
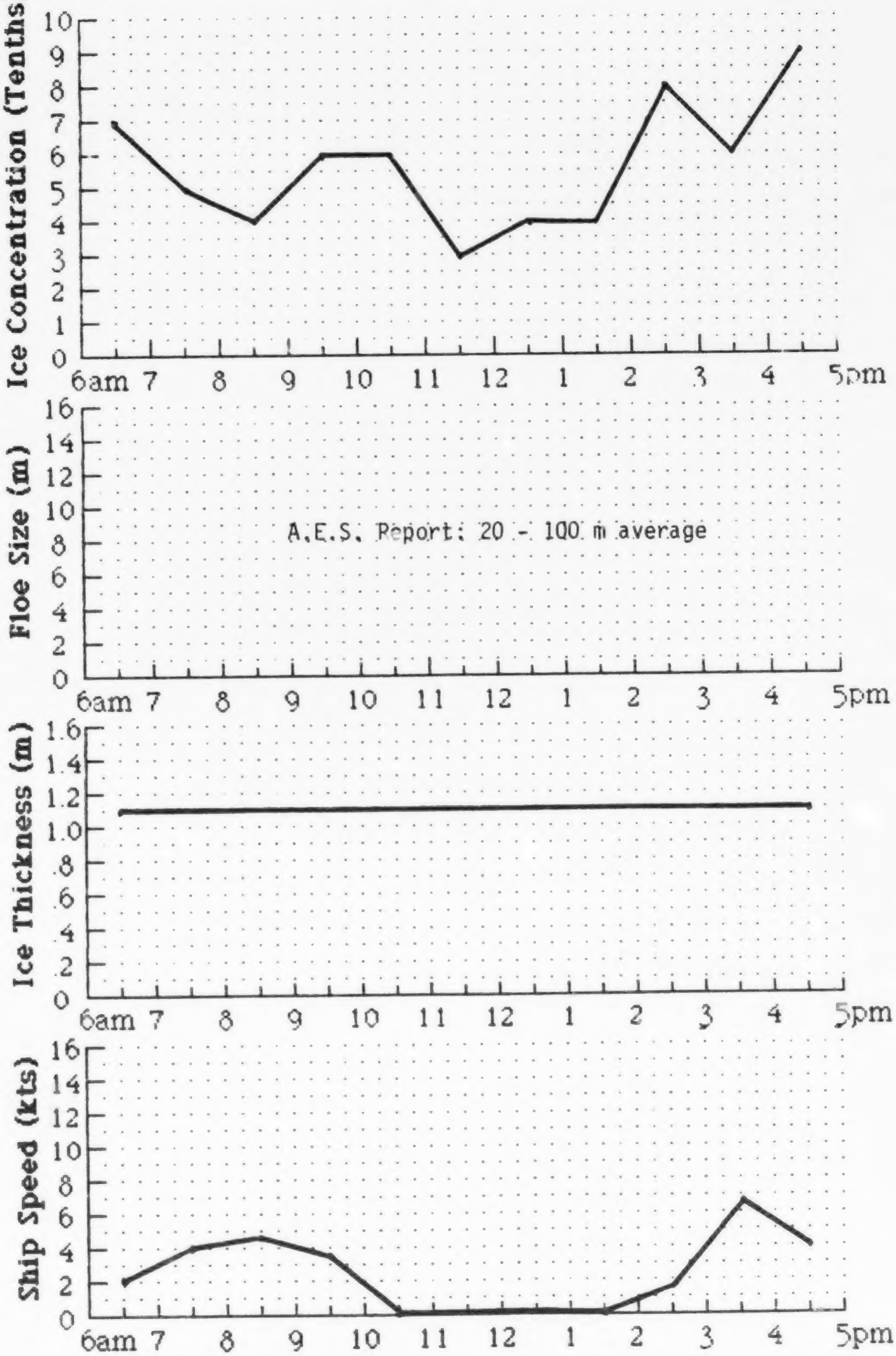


Figure 8.8 SHIP'S LOG DATA
March 22



A.E.S. report: 20 - 100 m average

Figure 8.9 SHIP'S LOG DATA
March 23



A.E.S. Report: 20 - 100 m average

Figure 8.10 SHIP'S LOG DATA
March 24

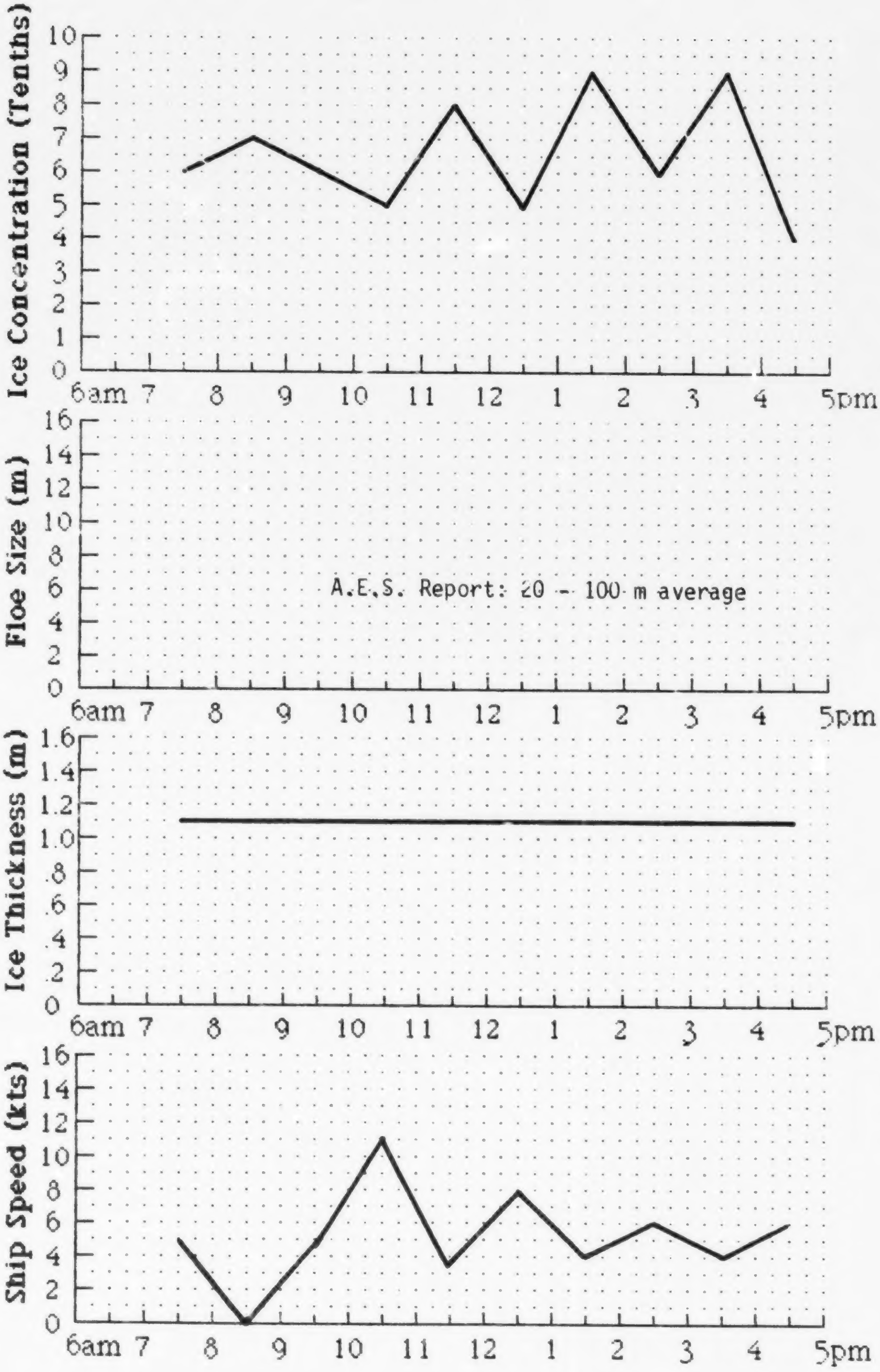
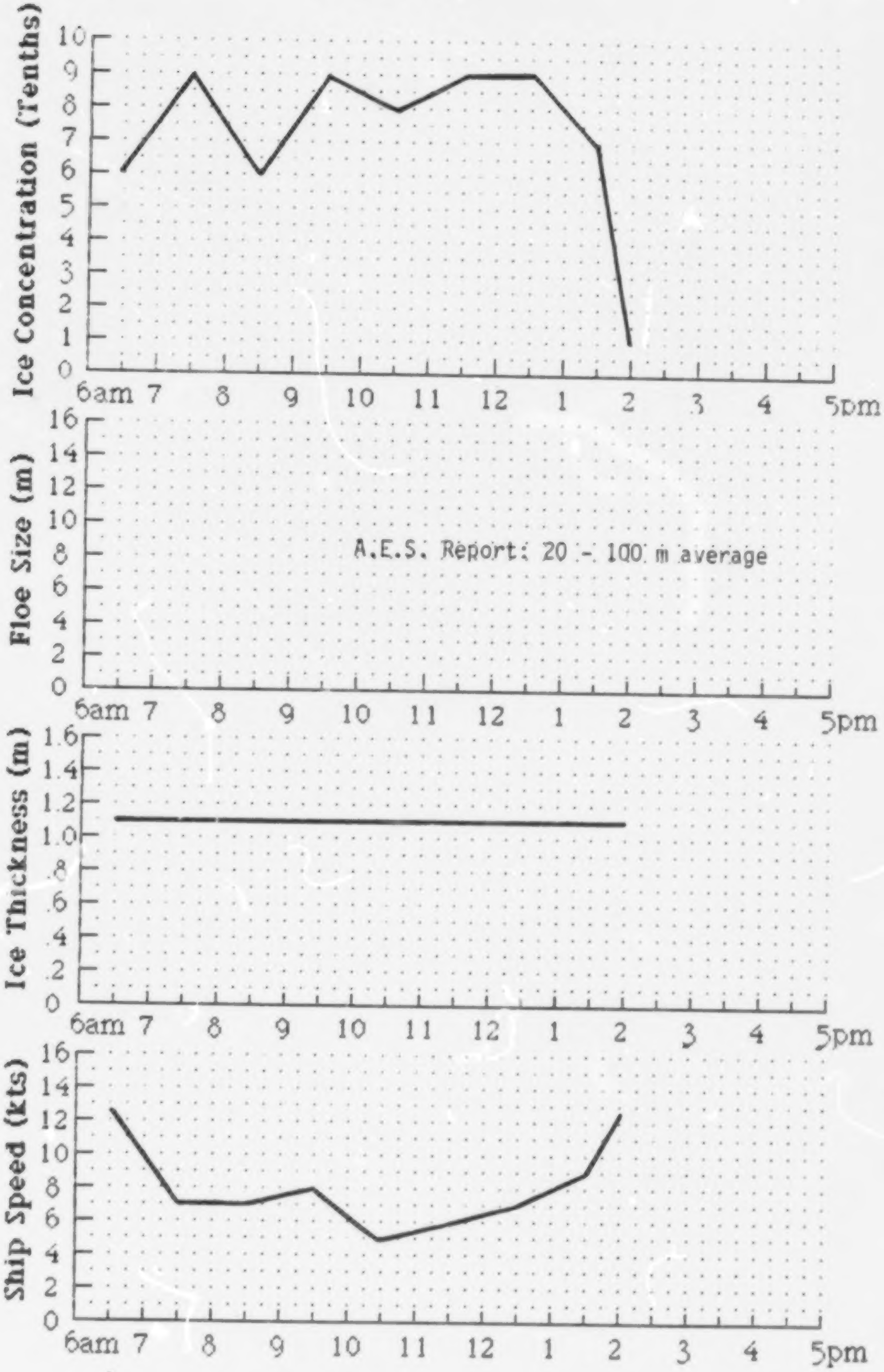


Figure 8.11 SHIP'S LOG DATA
March 25



March 21

Course was reversed on the 21st, heading south west parallel with the pack edge. Ice concentration and thickness was similar to that on the 20th, but weather conditions deteriorated with lower temperatures, snow, freezing rain and reduced visibility most of the day. Wind and wave directions changed to southwest at 10:30 am.

March 22

The ship fished around 52°N/51°W on the 22nd and experienced fairly uniform ice conditions all day with 6 to 9 tenths coverage, and thickness of about 1 metre. Traces of multi-year ice were also present. Air temperatures ranged from 0 to 2°C, the sky was clear and seas calm with westerly winds.

March 23

A similar location was held on the 23rd, but weather conditions deteriorated to rain and fog, from 07:30 to 15:30 hours. Wind and waves were from the southeast.

March 24

A southerly course was resumed on the 24th. Ice and weather conditions were similar to the previous two days

March 25

Weather conditions improved on the 25th, with clear sky, warmer air temperatures and wind shifting to the southwest. Ice concentration was heavier than the previous day until afternoon, when the south edge of the ice pack was reached.

8.3 Summary of All Data Collected

The useful strain data from the shipboard ice measurement trials consisted of 86 significant 5-minute blocks. Each data block in turn contained strain data from which to derive 10-20 distinct pressure events giving a total of 1250 distinct pressure events. The total number of impacts recorded for each sub-panel (on the basis of largest shear difference in the panel) is shown in Figure 8.12. From this it can be seen that the impacts are distributed relatively evenly over the panel although a large number appear at the outer sub-panels. The corresponding pattern of sub-panel maximum pressures is shown in Figure 8.13. The values across the stringer are indeed high as expected in light of the physical calibration results and must be discarded. The maximum value neglecting the stringer sub-panels is 644 kPa and in light of 1 MPa being a critical structural load, this appears quite reasonable.

On the following pages the pressure maximums along with the ship speed are presented in Table 8.2 with the corresponding ice data for each of the eighty-six 5-minute data blocks.

FIGURE 8.12

NUMBER of SUB-PANEL IMPACTS RECORDED on the CAPE BRIER

FR 62	61½	61	60½	60	59½	
						LOWER DECK
	0	20	31	0	52	
	142	38	7	61	111	
	105	15	10	9	74	STRINGER
	35	21	56	1	165	
	34	27	41	30	52	
	37	8	30	2	43	
						TANK DECK

FIGURE 8.13

MAXIMUM SUB-PANEL ICE PRESSURES MEASURED ON the CAPE BRIER

FR 62	61½	61	60½	60	59½	
						LOWER DECK
	18.71	318.65	201.35	25.79	363.49	
	385.00	348.29	254.76	249.27	644.56	
	6383.76	3831.79	7481.69	9193.29	1506.41	STRINGER
	529.40	131.76	377.88	167.89	315.80	
	288.13	172.13	564.06	477.30	383.11	
	340.89	163.85	220.00	462.96	352.35	
						TANK DECK

TABLE 8.2

Summary of Pressure and Ice Data

DATA BLOCK	DATE /TIME	P_{max} (kPa)	V_{SHIP} (kt)	t_{ice} (m)	FLOE DIAM. (m)	ICE COVERAGE (1/10's)	DESCRIPTION
Mar 20/84							
1	9:42	284	4.0	0.6	4.0	5	
2	9:59	130					Course generally
3	10:30	443	4.0	1.2	4.0	10	NE parallel to the
4	11:09	300					pack edge
5	11:34	193					
6	11:45	143					
7	12:27	352	8.0	0.8	7.0	8	
8	13:25	382					
9	13:37	257	10.0	1.1		4	
10	14:47	302	10.0	1.1		6	
11	15:04	118					
12	15:14	147					
13	15:23	219	6.0	0.8	11	8	
14	15:42	205					
15	15:52	305					
16	16:02	173					
17	16:14	46					
18	16:25	151	5.0	1.1	9	4	
Mar 21/84							
19	6.52	322					
20	7:01	584					Course generally
21	7:11	460					SW parallel to
22	7:29	132	3.0	0.8	9	9	pack edge
23	7:39	249					
24	7:50	174					
25	8:00	137					
26	8:52	159	4.0	0.8	15.0	8	
27	9:02	77					
28	9:11	39					
29	9:21	22					
30	9:32	106	3.0	1.1	13	6	
31	9:42	73					
32	9:53	163					
33	10:03	78					
34	10:14	325					
35	10:27	300	3.0	0.9	10	7	
36	11:13	253					
37	11:30	315	4.0	0.9	8	7	
38	11:56	477					
39	13:00	86					
40	13:24	168	5.0	0.8	4	7	
41	14:08	33					
42	14:18	158					
43	14:33	301	12	0.6		1	
44	14:45	340					
45	15.21	246	5	1.1	6	7	
46	15:43	247					
47	16:23	172	8	0.8	6	6	

TABLE 8.2

Summary of Pressure and Ice Data

DATA BLOCK	DATE /TIME	P_{max} (kPa)	V_{SHIP} (kt)	t_{ice} (m)	FLOE DIAM. (m)	ICE COVERAGE (1/10's)	DESCRIPTION
Mar 22/84							
48	11:19	209					Location 52°N/51°W
49	11:34	233	5	0.9		7	Uniform ice conditions
50	11.46	148					traces of multi-year ice
51	12:01	214					
52	14:04	487					
53	14:14	170					
54	14:38	194	4.0	1.1		7	
55	14:48	205					
Mar 23/84							
56	6:42	115	2.0	1.1		7	Similar location as
57	8:20	644	5.0	1.1		4	previous day
58	8:58	198					poor weather
59	14:58	181	2	1.1		8	
60	16:06	170					
61	16:17	237	6	1.1		6	
Mar 24/84							
62	7:38	359	5	1.1		6	
63	7:48	225					
64	11:23	243	4	1.1		8	Similar ice and weather
65	11:53	104					as previous two days
66	12:35	121	8	1.1		5	
67	12:45	358					
68	13:51	145					
69	14:22	222	6	1.1		6	
70	15:09	126					
Mar 25/84							
71	6:05	186					
72	6:37	363	12	1.1		6	
73	7:35	157	7	1.1		9	
74	7:44	148					Heavy ice conditions
75	8:09	228					
76	8:19	187	7	1.1		6	
77	9:37	254	8	1.1		9	Last day in ice
78	10:42	194	5	1.1		7	
79	10:53	184					
80	11:04	309					
81	11:16	212	6	1.1		8	
82	12:22	249					
83	12:32	181	7	1.1		8	
84	12:49	377					
85	13:21	385	9	1.1		6	
86	13:45	162					

8.4 Photographic Record

Photographs were taken to document the ice conditions and the icebreaking patterns around the ship. A total of 16 rolls (@ 36 frames) of film were used over the seven days in ice. There are two items that are seen in the photos which are important to the results. The photos show considerable old ice. It is not known whether any impacts with old ice were recorded, which would likely be more severe than first year ice. In most of the photos of impacts on the panel, the familiar cusp breaking pattern can be noted. This is important to know during the analysis.

The following figures are representative of the photographs. Figure 8.14 shows a mixture of old and new ice on March 19. Note the considerable freeboard on the old ice. Figure 8.15 shows a breaking pattern on March 19. Figures 8.16 and 8.17 show similar situations on March 20. Figures 8.18, 8.19, 8.20 and 8.21 show new ice and icebergs on March 21 and March 25.

FIGURE 8.14: MAR.19 - OLD & NEW ICE

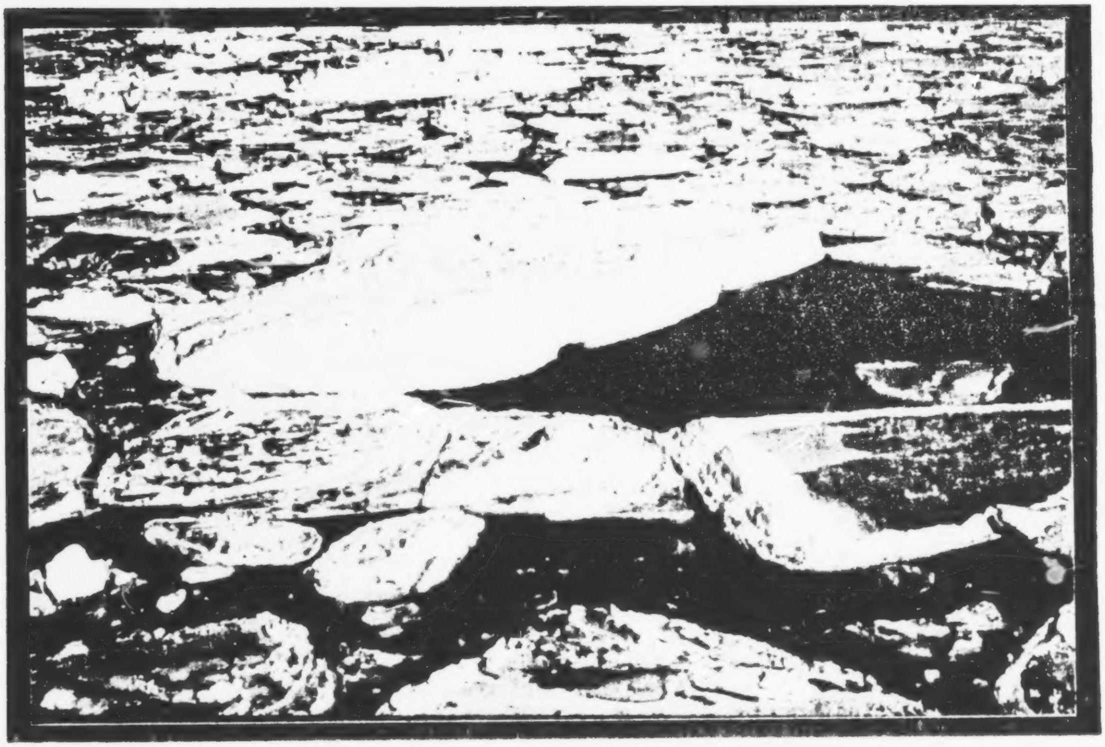


FIGURE 8.15: MAR.19 - BREAKING PATTERN

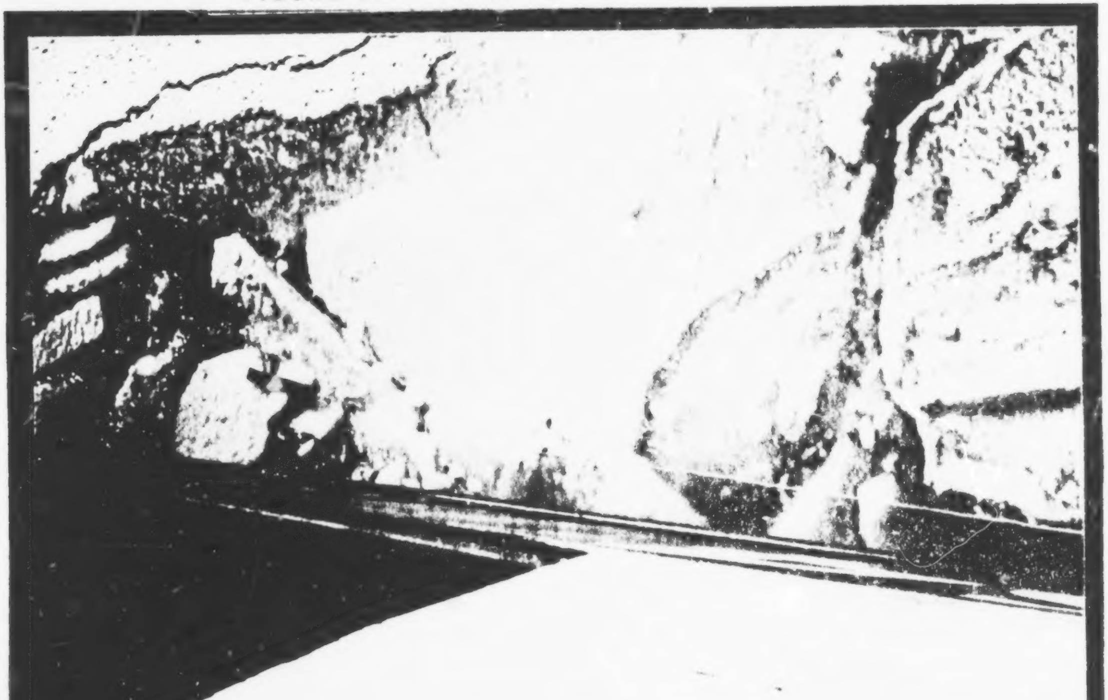


FIGURE 8.16: MAR.20 - OLD & NEW ICE

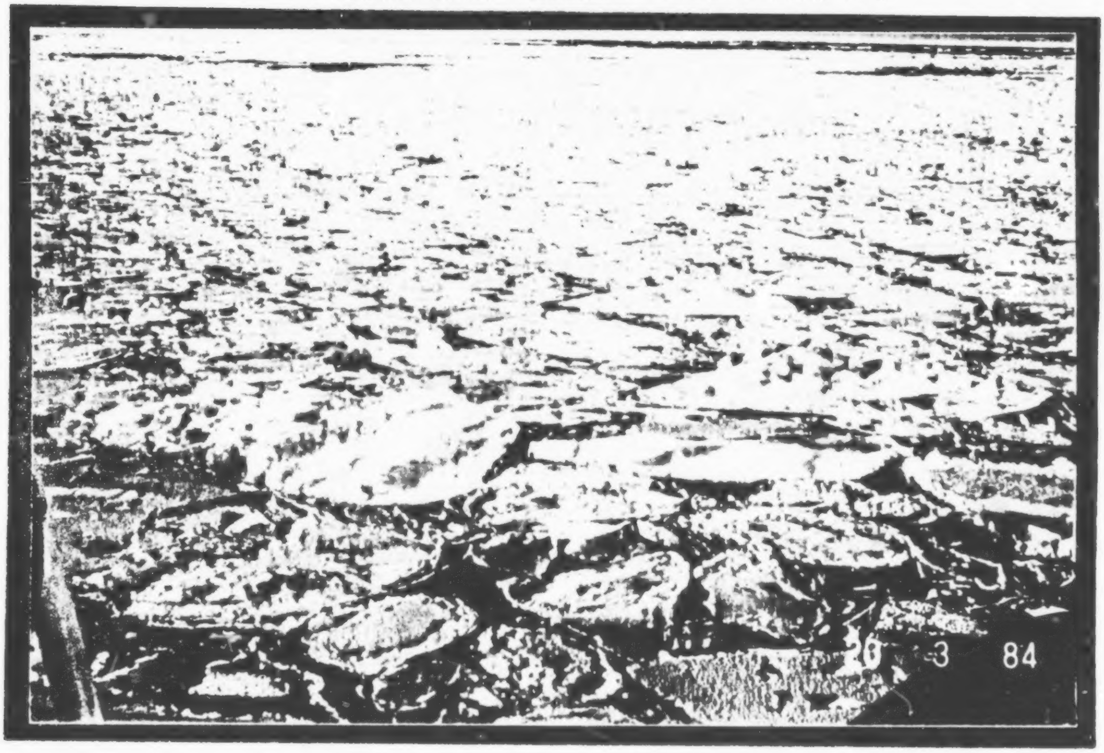


FIGURE 8.17: MAR.20 - BREAKING PATTERN

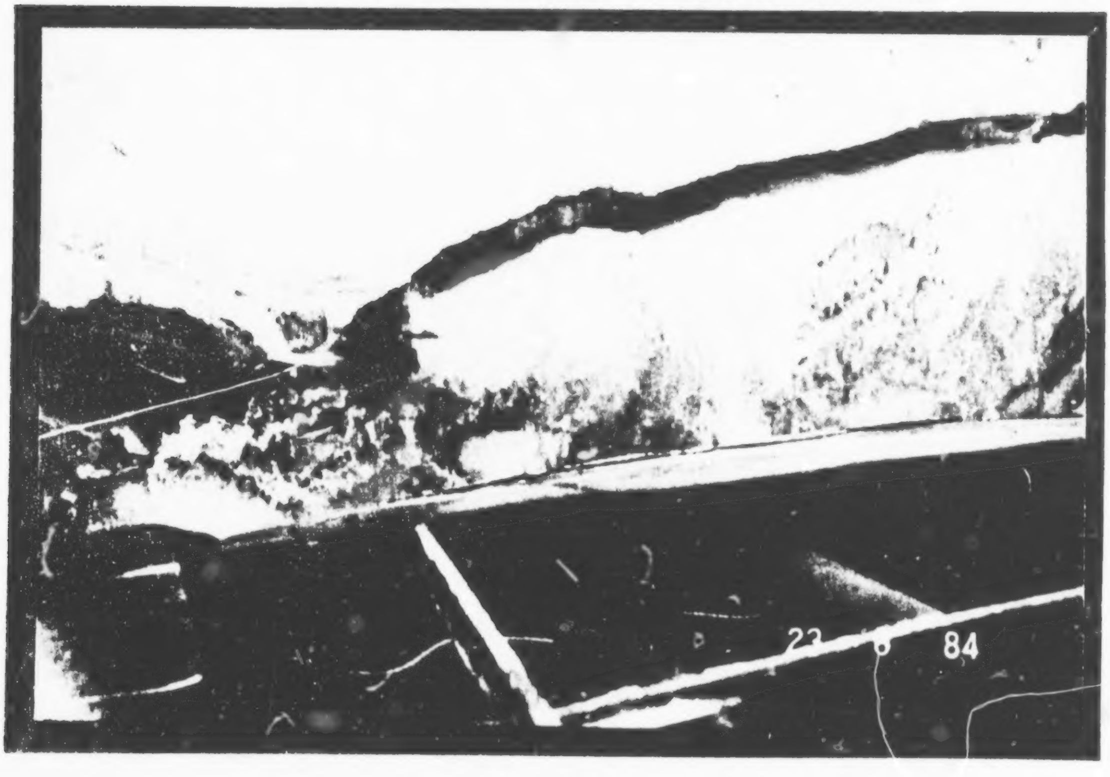


FIGURE 8.18: MAR.21 - NEW ICE

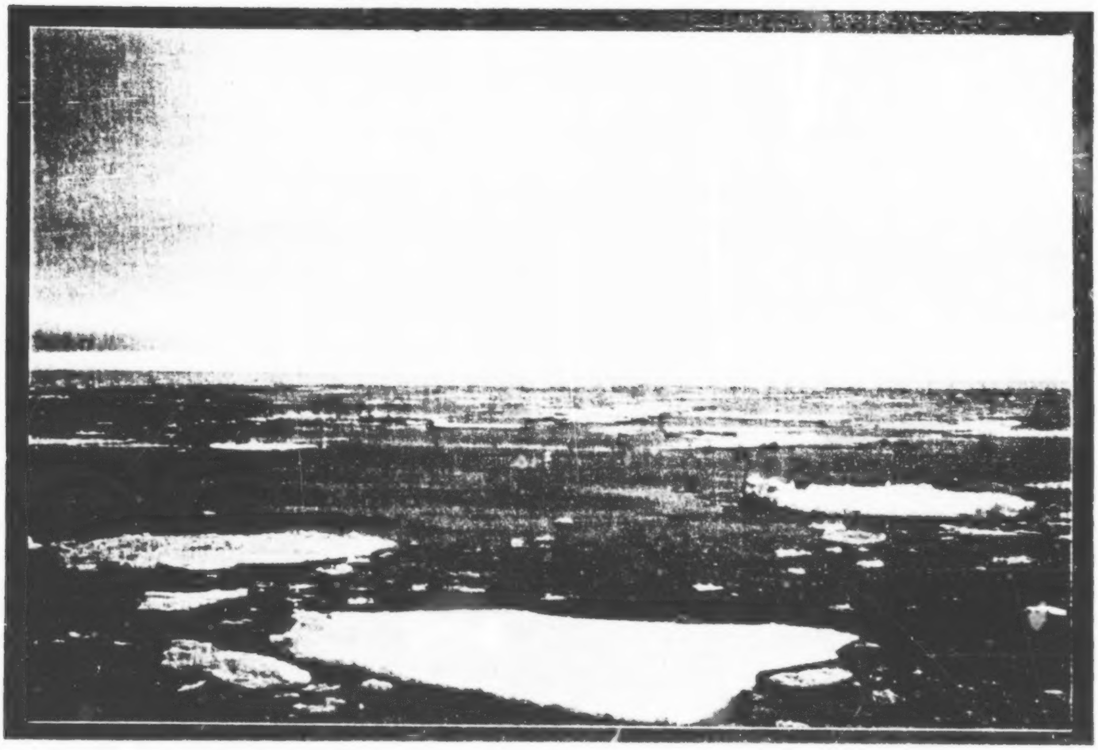


FIGURE 8.19: MAR.21 - SEA ICE/ICEBERG

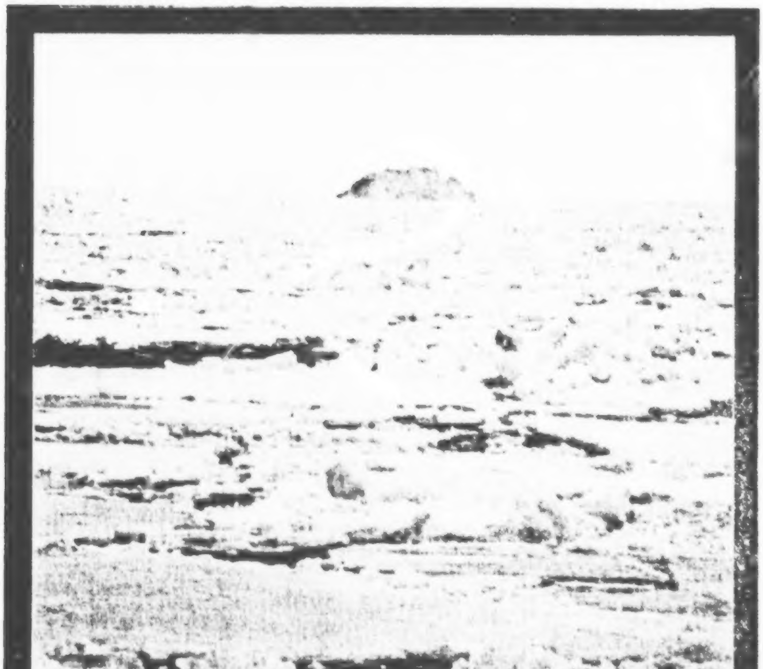


FIGURE 8.20: MAR.25 - SEA ICE/ICEBERG

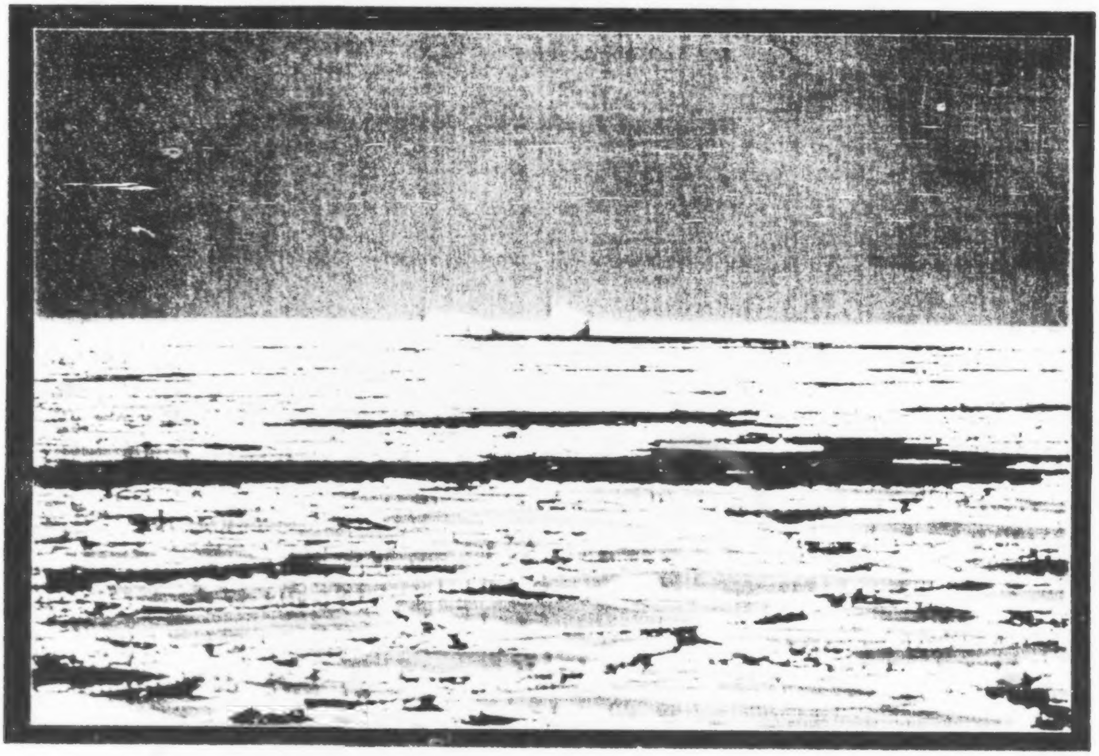
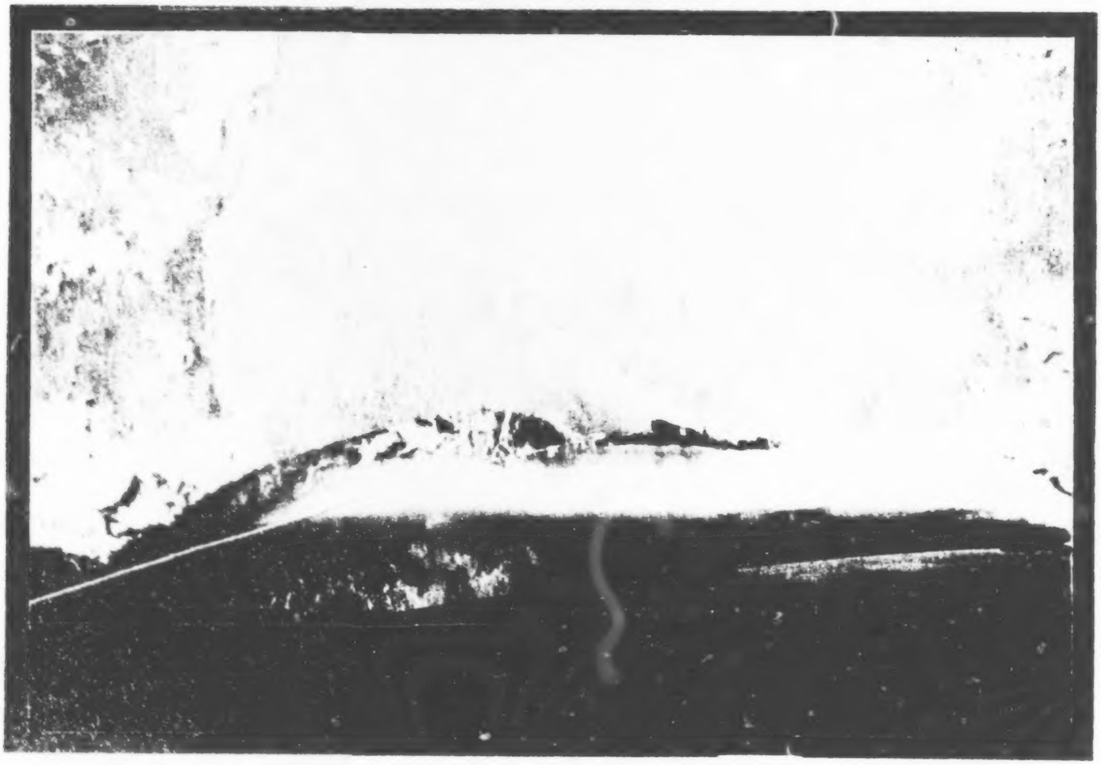


FIGURE 8.21: MAR.25 - CUSP BREAKING IN THIN ICE



9. ANALYSIS OF DATA

9.1 General

Data was gathered in 5-minute segments. If the measured strain exceeded a preset threshold (50 microstrain), a complete set of readings was taken (see Section 5). This complete set of readings is referred to as an "event", although several impacts may have taken place within the 5 minutes. 86 events were recorded during the seven days in ice.

9.2 Pressure vs. Area and 3-D Plots

The instrumented panel contains 30 sub-panels (.108m^{2}each). During each of the 86 5-minute events, 35 time slices of ice pressures were measured. Figures 9.1 through 9.10 show 3-dimensional pressure plots and pressure versus area plots, of the peak force and peak pressure time slices, for the ten highest pressure events. In many cases the peak force and peak pressure occurred at the same time.

Figure 9.1 is illustrative of two of the problems encountered. The reader will note that there appears to be three distinct peaks. When considering that all of the gauges on row 4 (the stringer) and gauges at frames 2 and 4 on row 6 are always set to zero, the reader will realize that these three peaks may well have been one larger peak. Due to the gauge malfunctions it was decided to only calculate pressure/area curves for a maximum of 9 sub-panels (1 neighbour panel on all sides, surrounding the peak).

The lower diagrams in Figures 9.1 to Figure 9.10 show plots of average pressure vs. specific area. A peak pressure of .644 MPa was recorded. Most of the plots show the typical "concave down" shape. Those that are a straight line result from a single peak surrounded by zero's.

Figure 9.11 shows the largest pressure/area curves on one plot. Again the concave shape can be seen in the envelop.

FIGURE 9.1
3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 306

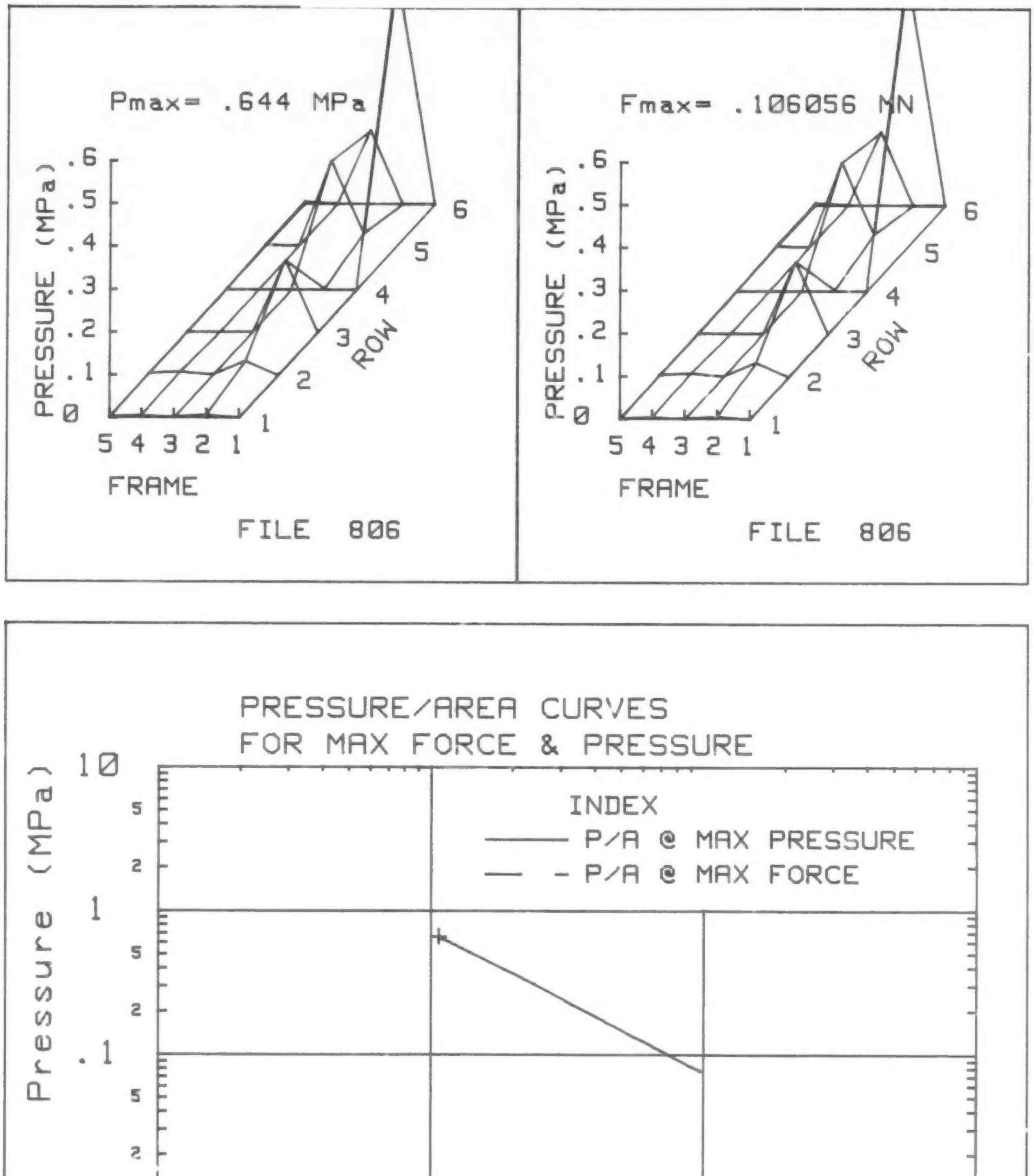


FIGURE 9.2
3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 511

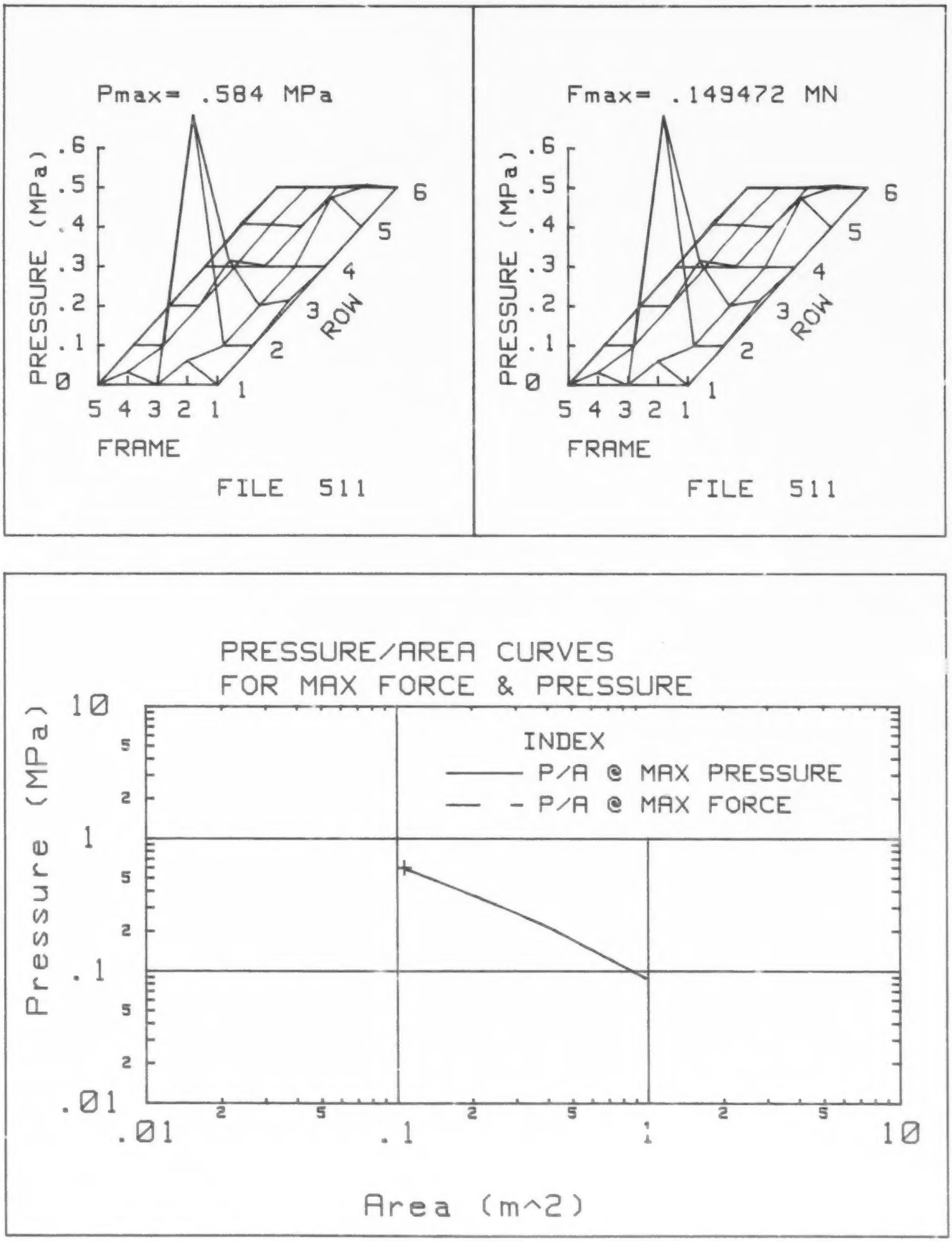


FIGURE 9.3

3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 801

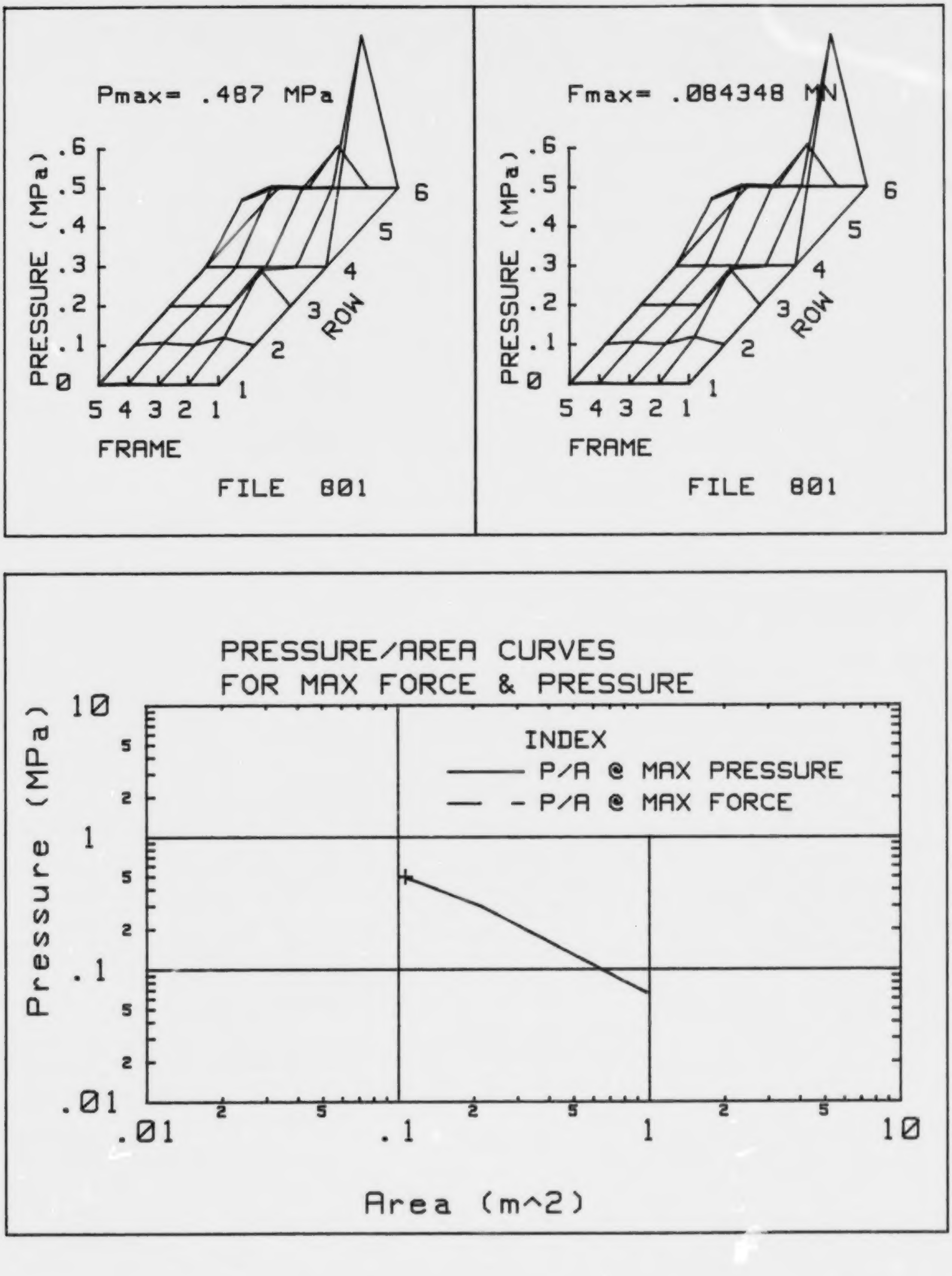


FIGURE 9.4
3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 613

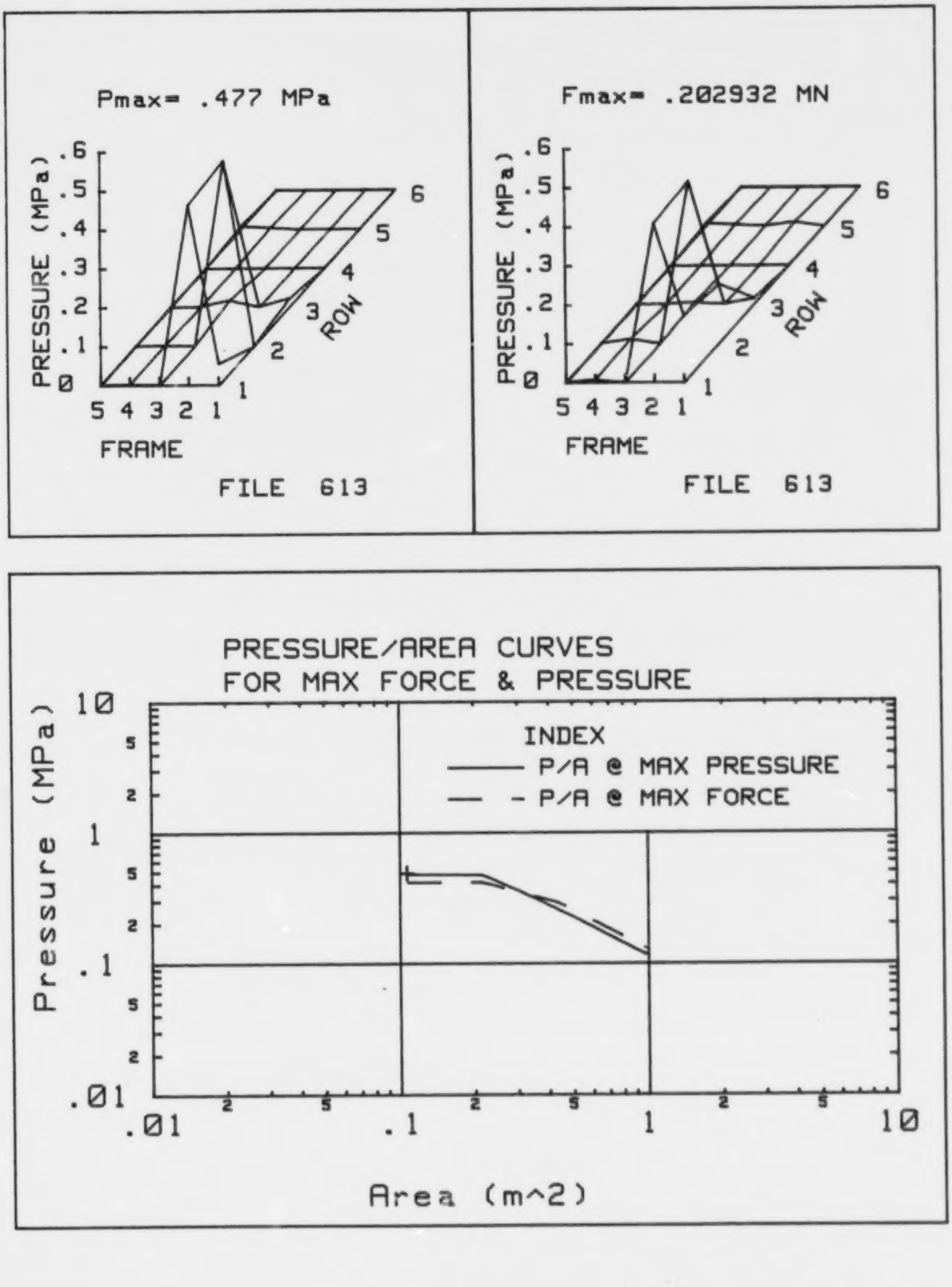


FIGURE 9.5

3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 512

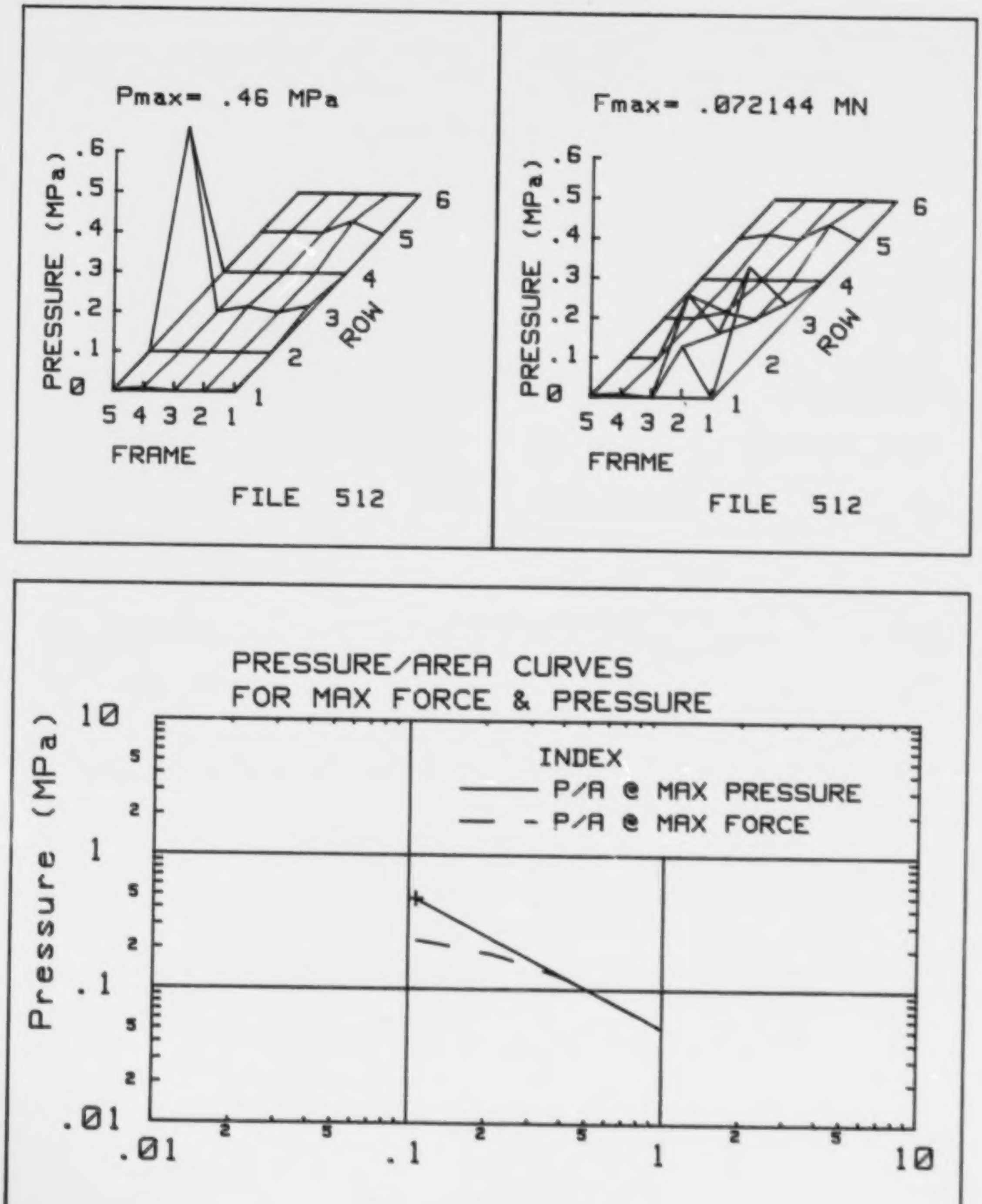


FIGURE 9.6
3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 403

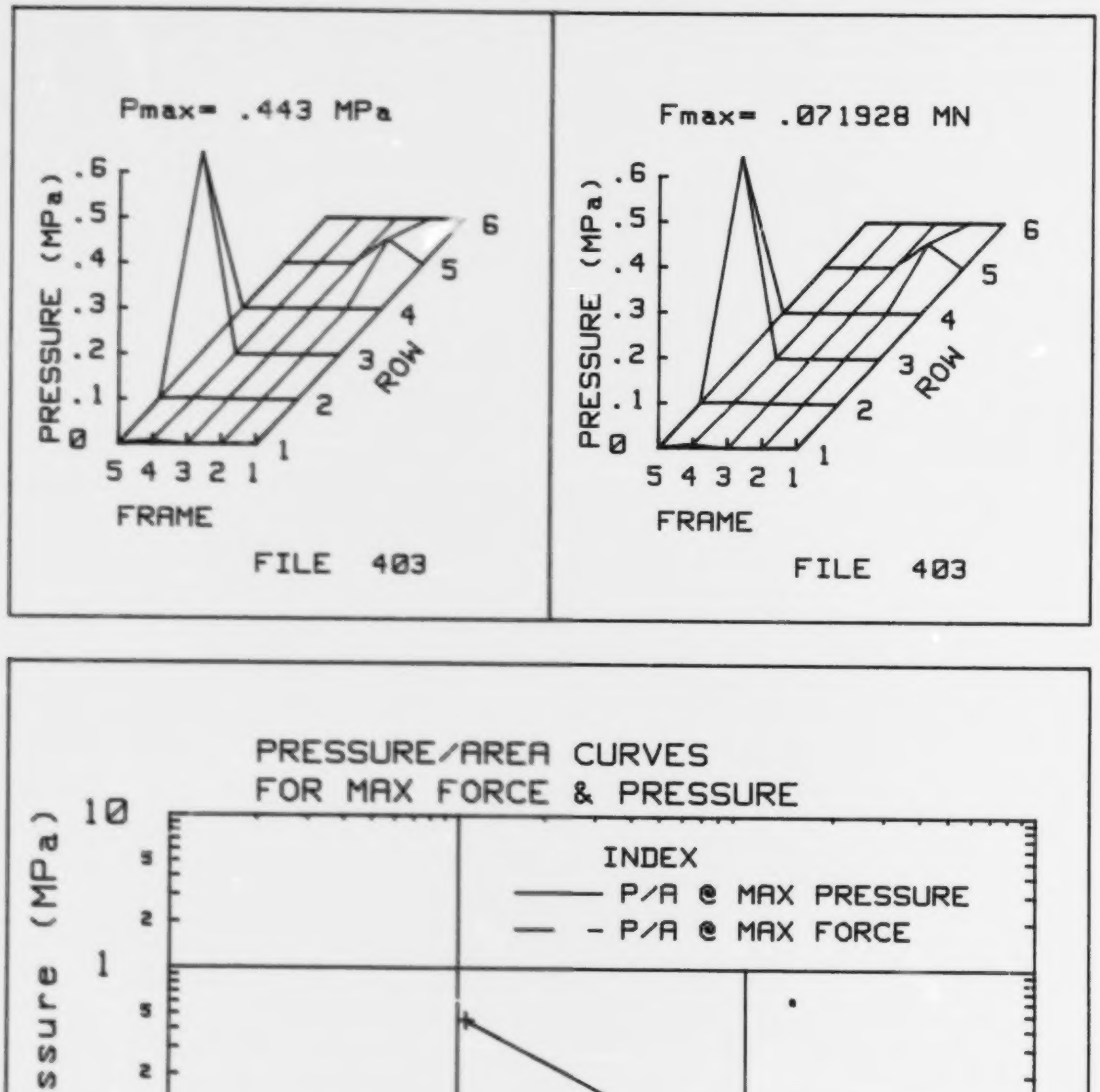


FIGURE 9.7
3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 1204

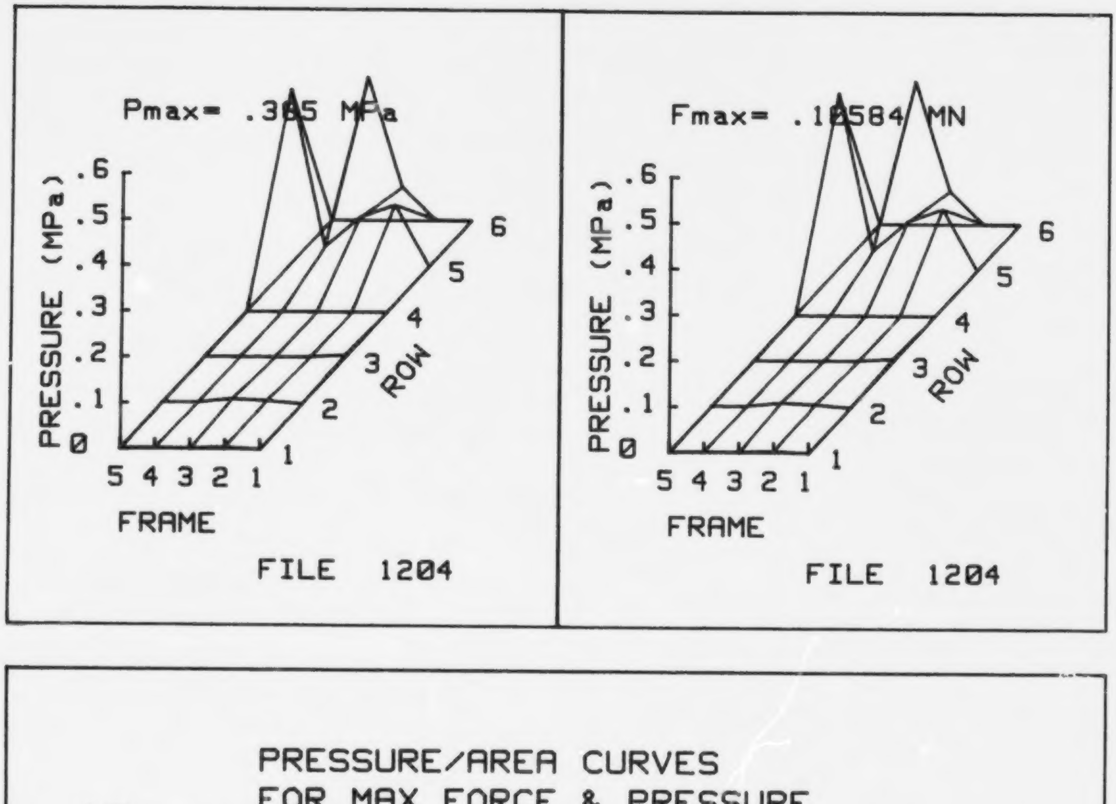


FIGURE 9.8
3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 408

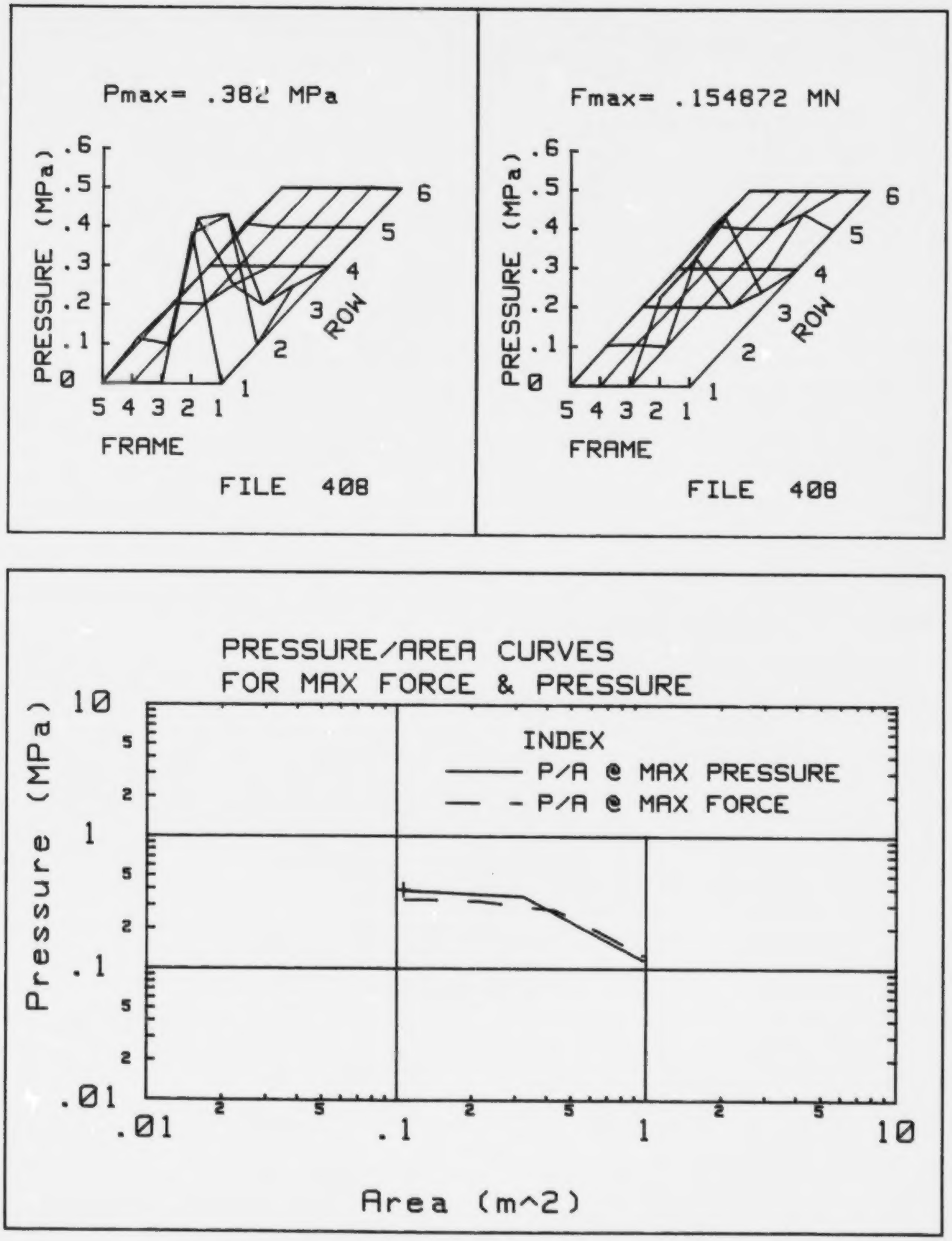


FIGURE 9.9
3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 1203

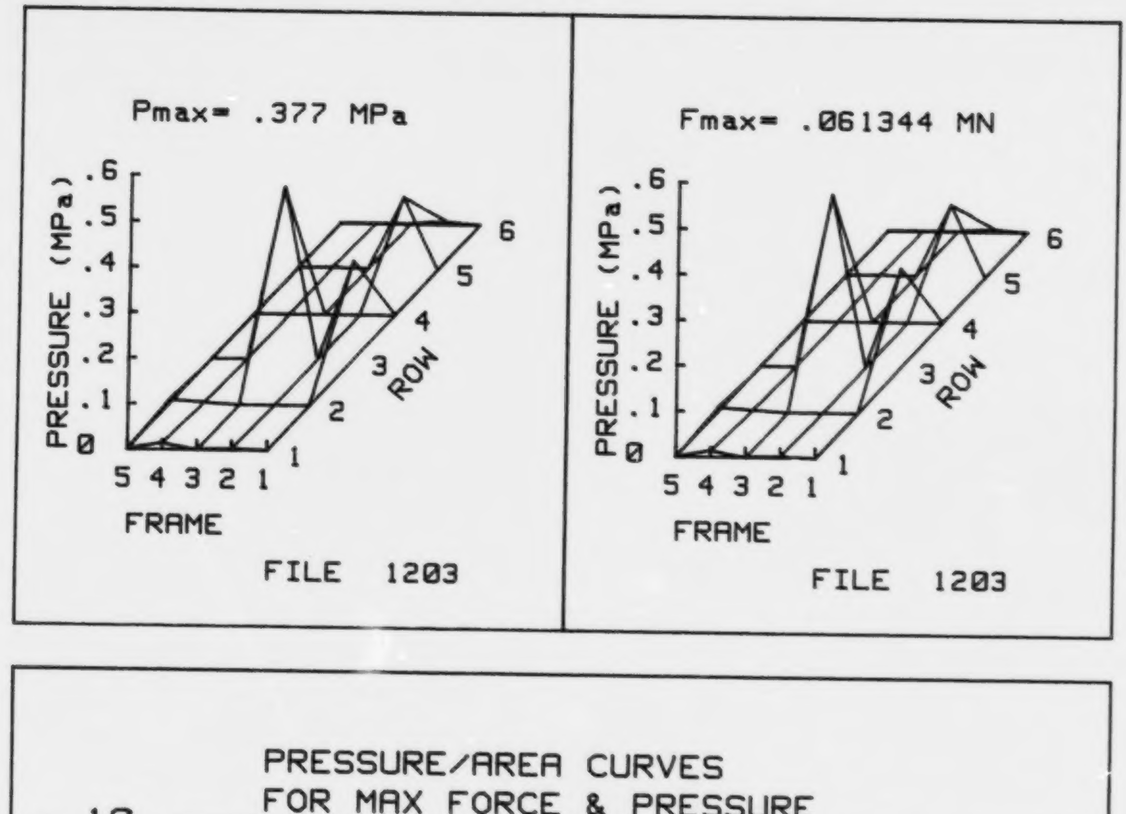


FIGURE 9.10
3-DIMENSIONAL AND PRESSURE/AREA
PLOTS AT TIMES OF PEAK PRESSURE
AND FORCE FOR EVENT NO. 1009

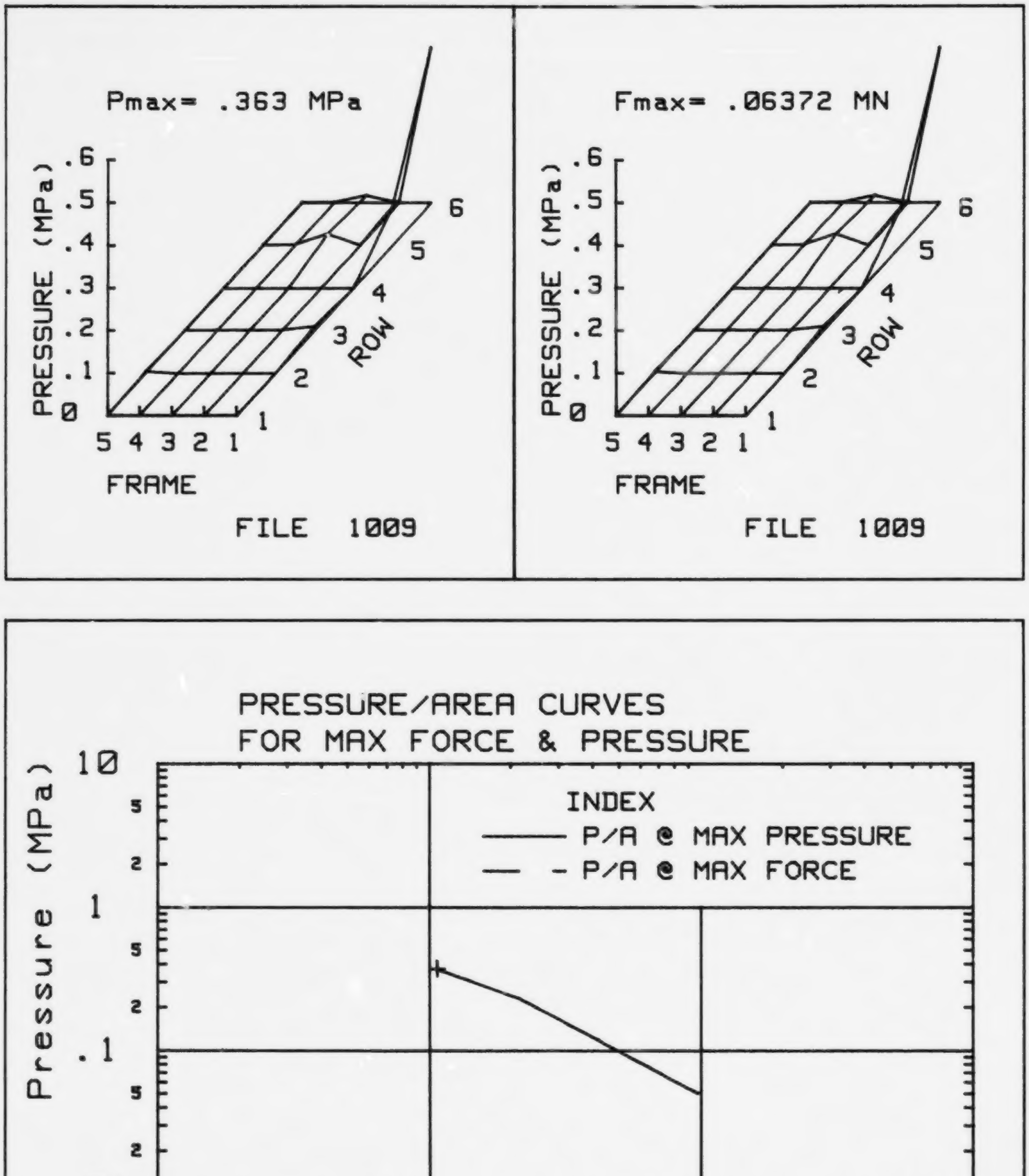
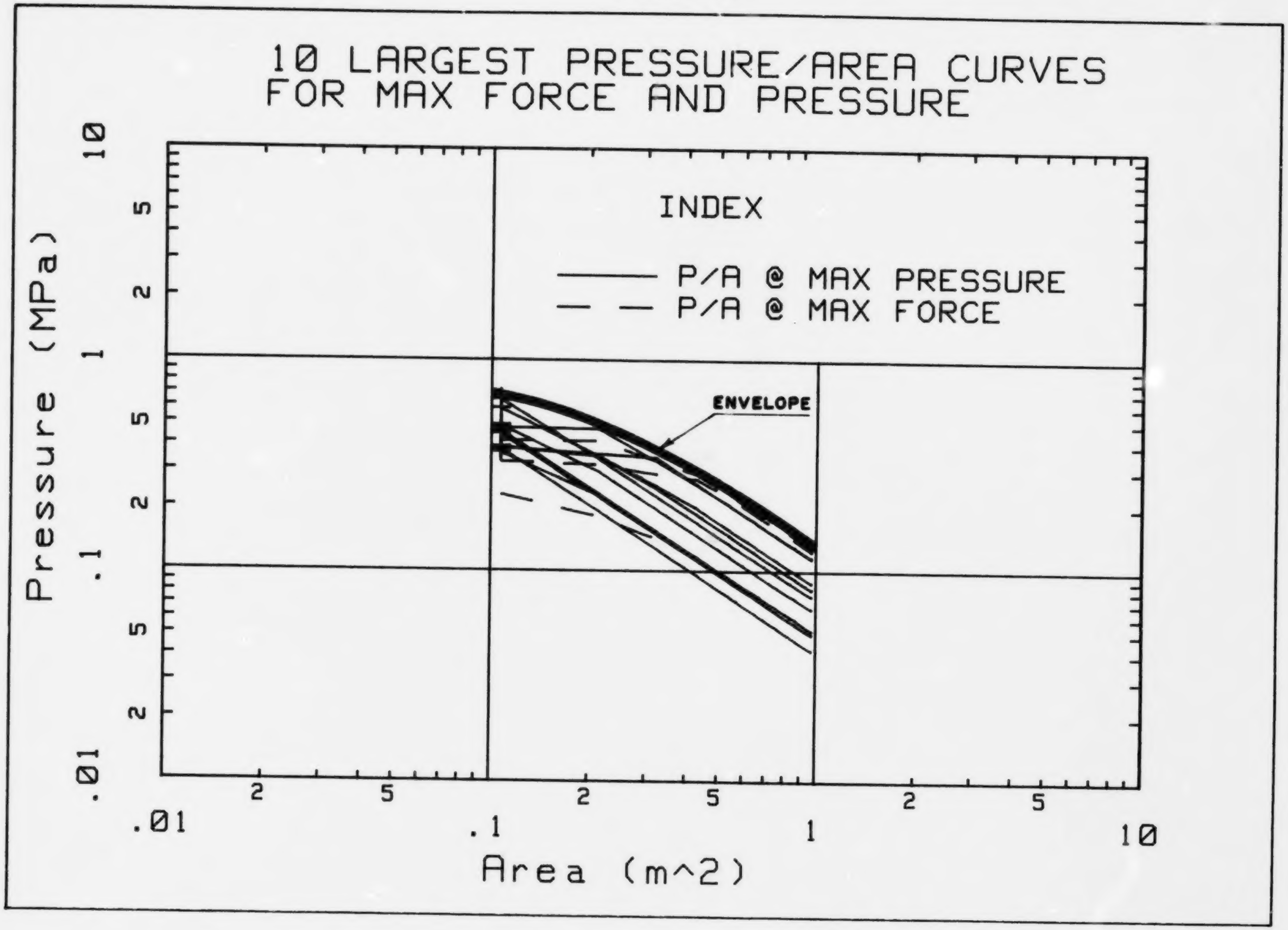


FIGURE 9.11


10 LARGEST PRESSURE/AREA CURVES
FOR MAX FORCE AND PRESSURE
INDEX
P/A @ MAX PRESSURE
P/A @ MAX FORCE
ENVELOPE
Pressure (MPa)
.01
2
5
.1
2
5
1
2
5
10
Area (m^2)
.01
2
5
.1
2
5
1
2
5
10

9.3 Extreme Value Statistics

The eighty-six 5-minute segments have been analyzed using extreme value statistics, in an attempt to predict highest expected pressures.

Figure 9.12 shows the extreme values of pressure for 4 areas (.108 m^2, .216 m^2, .432 m^2, and .864 m^2) plotted on a Gumbel Type I paper. The straight dashed lines through the data are for the Type I equation:

$$F(p) = e^{-e^{-\alpha(A)(p-u(A))}} \tag{9.1}$$

where $\alpha(A) = 35.1 \times A + 6.20$ (9.2)

$u(A) = .02/A$ (9.3)

A = area (m^2)

p = ice pressure (MPa)

$F(p)$ = Probability that the measured pressure will be less than "p" during a 5-minute sample, anywhere on the panel.

The best match occurs for 1 sub-panel. As the area increases the measured data appears more and more concave upwards, suggesting the likelihood of a Gumbel Type II distribution for large areas.

FIGURE 9.12

GUMBEL TYPE I EXTREME VALUE
STATISTICS

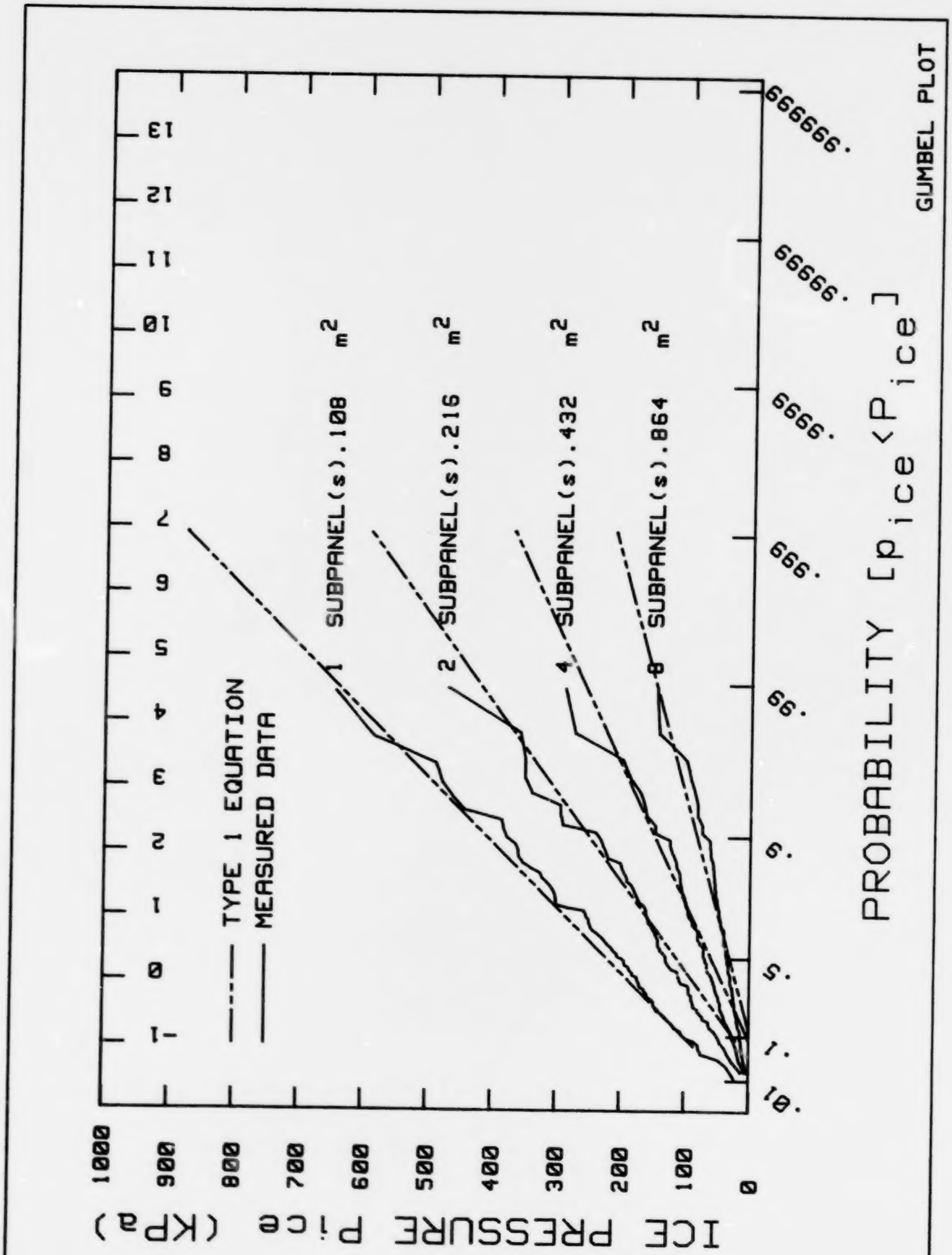


Figure 9.13 plots the same measured data on Type II extreme value paper. Here the best fit is for the largest area (8 sub-panels). The straight dashed lines through the data are for the Type II equation;

$$F(p) = e^{-(\frac{U2(A)}{p}\;K(A)} \qquad (9.4)$$

where $U2(A) = .0252/(A^{.9})$ (9.5)

$k(A) = 2.63 + .044/A$ (9.6)

A = area (m^2)

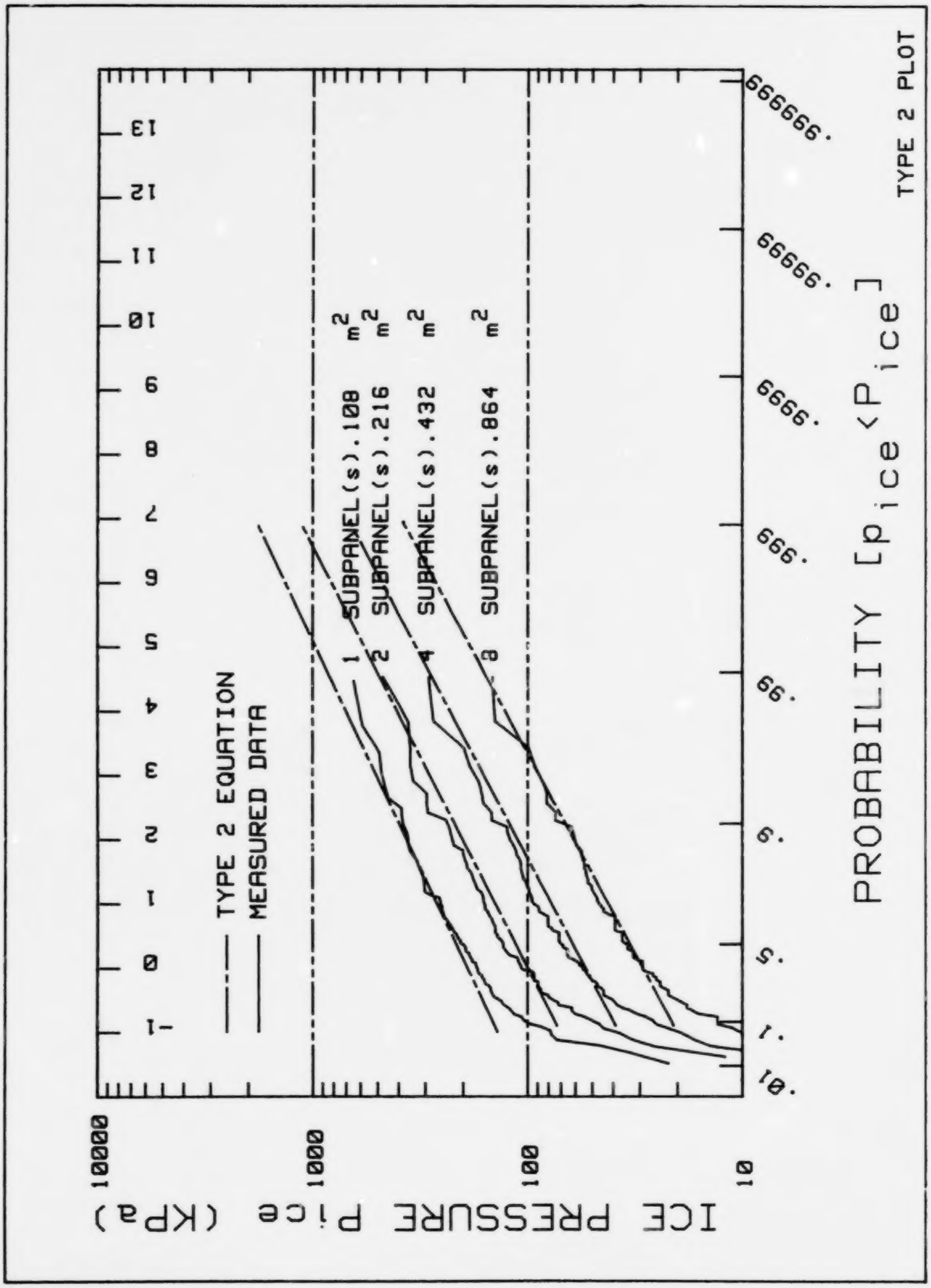
P = ice pressure (MPa)

$F(p)$ = probability that the measured ice pressure will be less than "p" during a 5-minute sample, anywhere on the panel.

By rearrranging equations 9.1 or 9.4 it is possible to construct a pressure/area equation for any given probability. Figure 9.14 shows a comparison of extrapolated Pressure/Area curves for Type I and II equation for probabilities of .01, .001 and .0001 (1%, .1% and .01%). There is clearly considerable disagreement between Type I and Type II extrapolations to the lower probabilities.

FIGURE 9.13

GUMBEL TYPE II EXTREME VALUE
STATISTICS

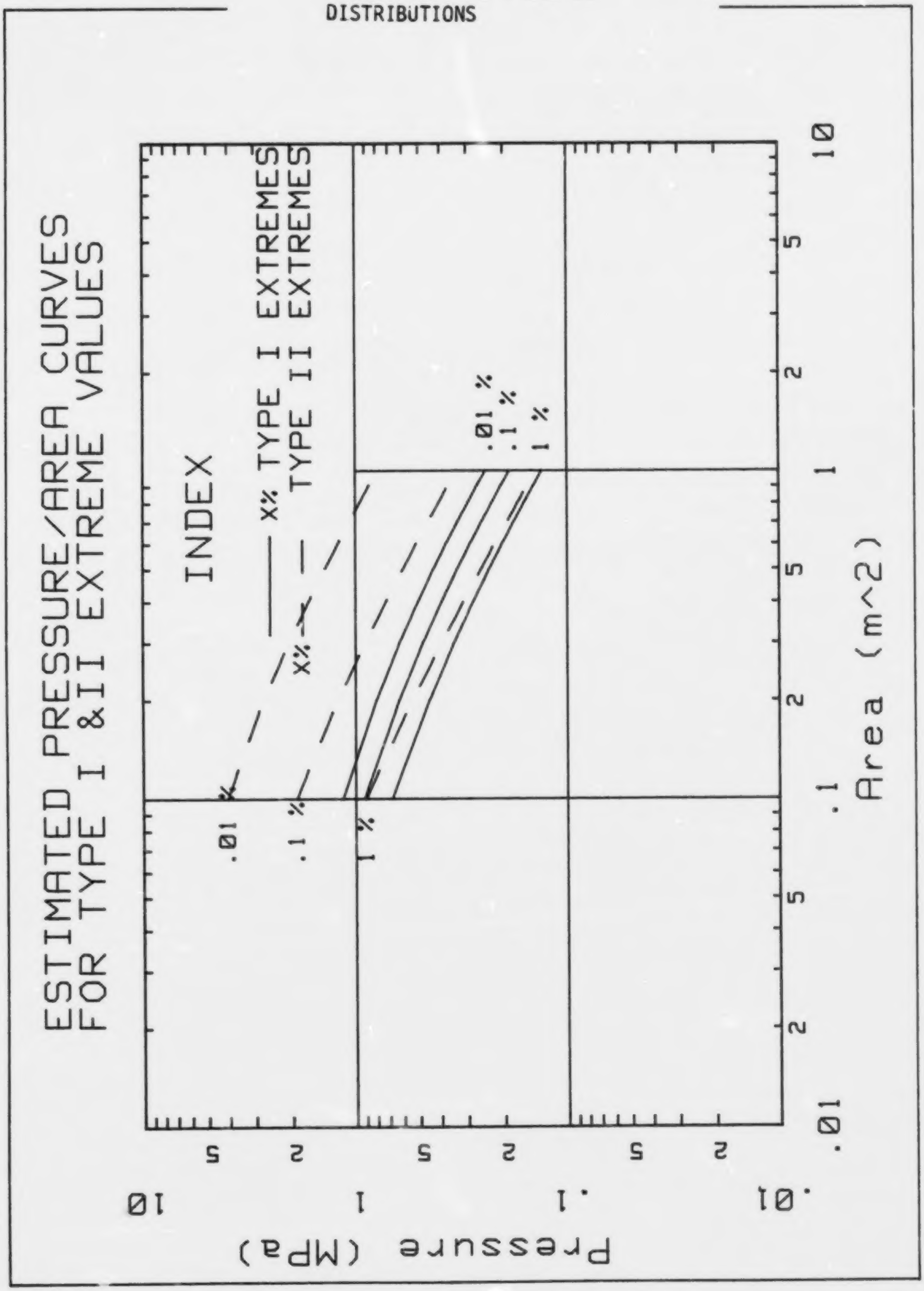


The basic process of ice failure must be considered when attempting to choose the correct extreme value distribution. The Type I distribution is valid for additive (average strength) processes, while the Type II is valid for multiplicative (least strength) processes. When breaking ice in bending there are two fundamental processes taking place, local edge crushing and cusp fracture. The local edge crushing phenomena is not well understood. It could well be that there exists some small characteristic crushing length, much smaller than the panel size. If this were the case then the single panel pressure would be an average of many small crushing areas and would approach a Type I (as it has). For larger areas the pressure is dependent on the peak force which is dependent on the cusp strength. It appears that the cusp strength is a Type II variable which is quite possible, since the cusp is likely to fail at a weak link.

Clearly the data raises many questions. A more complete understanding of the mechanics of ice failure is needed.

FIGURE 9.14

PREDICTED EXTREME PRESSURE/AREA
PLOTS FOR TYPE I AND II
DISTRIBUTIONS



9.4 Expected Stresses

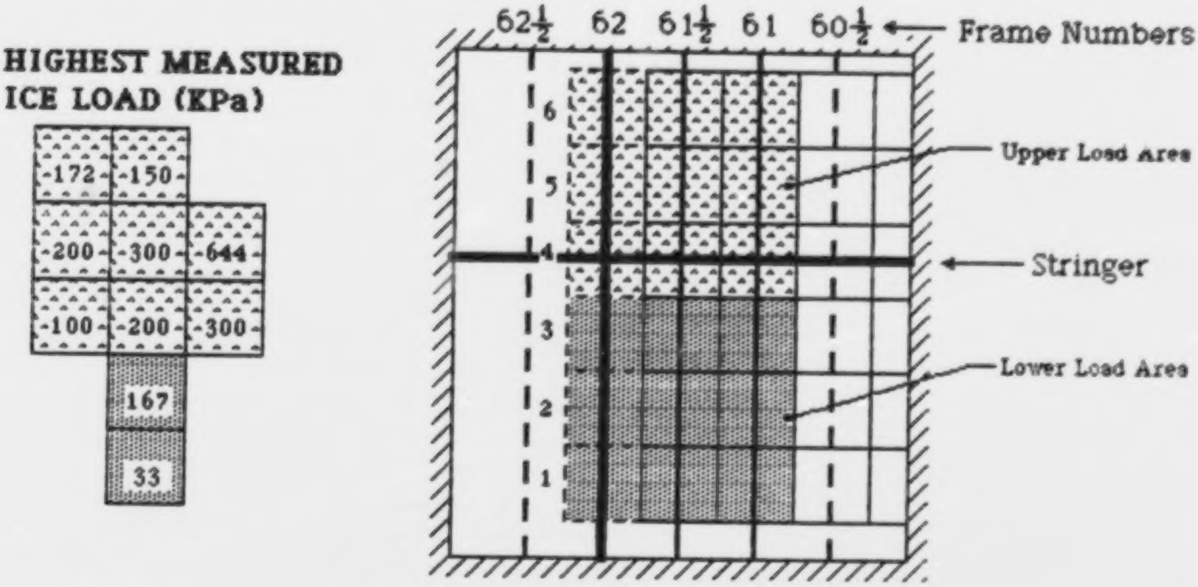
The instrumentation system was designed to monitor ice loads by measuring shear strains in the web of the main frames. In order to determine the critical stresses in the structure, it is necessary to apply the derived ice loads to the finite element model. The critical stresses are in fact the bending stresses in the main frames, stringer and shell plating. Shear and torsional stresses are not critical.

Four loads were applied to the structure in six ways, so that stresses could be determined for a range of circumstances. Figure 9.15 illustrates the load levels and positions of application. The first load was a modified form of the highest measured load. The gaps in the measurements (due to reasons discussed earlier) were filled in with reasonable estimates of ice pressure. This load was applied to the upper portion of the finite element model. Three derived ice loads of decreasing probability are also shown in Figure 9.15. These loads were derived from the probabilistic pressure versus area curves shown in Figure 9.14 (for a Type I extreme value distribution).

Conversion from percentage probabilities to time (i.e. weeks operating in ice) is accomplished by considering the total area of the bow and the number of impacts during the testing period. Eighty-six impacts were recorded during a one week period, on a panel that covers at most 10% of the bow area waterline. Therefore a load of .1% probability could be expected once per week, somewhere on the bow, on a .01% load could be expected every ten weeks (of operating in ice).

The expected stress levels as a percentage of yield stress are shown in Figure 9.16. The stresses range from 23% to 61% of yield depending on the circumstances. With load case 6 being expected every ten weeks, it is clear that the ship is at a risk. Stresses should not normally be allowed to exceed 50% of yield stress.

FIGURE 9.15 LOCATION AND MAGNITUDE OF LOADS APPLIED TO THE FINITE ELEMENT MODEL


HIGHEST MEASURED ICE LOAD (KPa)
-172-
-150-
-200-
-300-
-644-
-100-
-200-
-300-
167
33
62½
62
61½
61
60½
Frame Numbers
6
5
4
3
2
1
Upper Load Area
Stringer
Lower Load Area

DERIVED ICE LOADS (KPa) of DECREASING PROBABILITY

Ice Load of 1% Probability

39	207	30
53	645	118
19	76	23

Applied to ░ & ▒

Ice Load of .1% Probability

59	311	45
79	867	177
29	114	36

Applied to ▒

Ice Load of .01% Probability

78	415	60
106	1107	235
39	152	48

Applied to ░ & ▒

FIGURE 9.16 Expected Stresses as a Percentage of Yield Stress for Measured and Projected Loads

LOAD CASE	Main Frame Bending	Shell Plate Bending	Stringer Bending
1. Peak Measured	23%	∼	∼
2. 1% Probability Upper Area	30%	∼	∼
3. 1% Probability Lower Area	40%	∼	∼
4. .1% Probability Lower Area	59%	∼	∼
5. .01% Probability Upper Area	44%	9%	13%
6. .01% Probability Lower Area	61%	7%	19%

Note: Bending Stresses Exceeded All Other Stresses

Tripping

Main frames are potentially subject to lateral instability, normally called tripping, which tends to reduce the elastic and ultimate strength. Canted frames, such as those found in the CAPE BRIER are particularly sensitive to tripping. Following the analysis described in [12] the inequality (see Figure 9.17):

$$\sin \alpha \leq \frac{t_w^2 \, E/\sigma}{20 \, a \, (1-4h/3a)} \; \frac{1}{(A_f + 0.5A_w} \; \frac{A_f^2 \, h}{A_w^2 \, t_f} + 2 \qquad (9.7)$$

determines if tripping is possible.

where

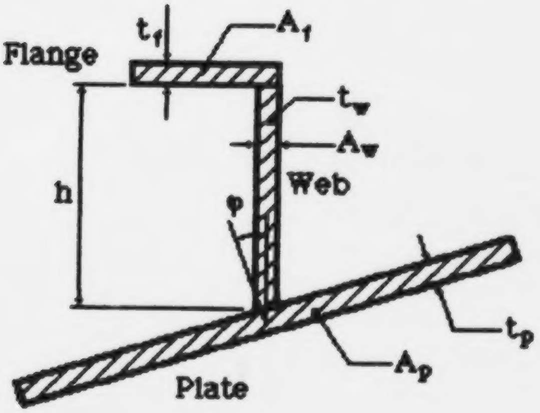
	CAPE BRIER
α = angle between frame and normal to plate	30°
tw = web thickness	13 mm
E = Young's Modulus	206000 MPa
σ = yield strength	235 MPa
a = span of frame	1500 mm
h = height of web	200 mm
A_f = area of flange	1300 mm^2
A_w = area of web	2600 mm^2
t_f = flange thickness	13 mm

which results in:

$$\sin 30^\circ \leq 2.70$$

which indicates that the frame will not trip.

FIGURE 9.17 The Elements of a Canted Angle Frame


t_f
A_f
Flange
t_w
A_w
Web
h
φ
t_p
A_p
Plate

9.5 Approach to Design Loads on Fishing Vessels

In order to effectively design against ice loads, the maximum expected ice load over the useful life of the vessel must be determined. 86 events were collected during seven days in ice over an instrumented area of $2m^2$. The useful life of the ship is say 20 years, with a total of 600 days in ice (30 days/year). It is also necessary to account for the difference between the instrumented panel area ($2m^2$) and the portion of the bow likely to see ice loads (say $35m^2$). Therefore the total increased number of events is:

$$M = 300/7 \times 35/2 = 750 \text{ times}$$

The design probability is;

$$1 - \frac{1}{86 \times 750} = .99998$$

This represents an extrapolation of 3 orders of magnitude beyond the measured data. Refering again to Figures 9.12 and 9.13 it can be seen that the expected pressures for probabilities of .99998, over 1 sub-panel are 1.25 MPa (if Type I) and 6.5 MPa (if Type II). For an area of 4 sub-panels (typical of frame loading) the expected pressures are .54 MPa (if Type I) and 3.5 MPa (if Type II). Clearly there is a need to gather much more data and establish the appropriate types of distributions.

The calculated strengths of the plating and framing on the CAPE BRIER are currently;

$$P(\text{plate}) = 2\,(t/s)^2\sigma$$
$$= 1.27 \text{ MPa}$$

where $P(\text{plate})$ = Ice pressure to cause yield (MPa)
t = plate thickness (= 13 mm)
s = plate span (= 325 mm)
σ = yield strength (= 235 mm)

$$P(\text{frame}) = \frac{10\ \sigma z}{b^2\ s}$$

$$= 1.38 \text{ MPa}$$

where z = section modulus (= 430159 mm³)
b = frame span (= 1500 mm)

While these calculations do not account for the angle between the frame and the shell or tripping, they do indicate an imbalance much in favour of the framing.

This data represents a first insight into the ice loads that fishing vessels can experience. While some valuable data has been gathered, it is not yet possible to outline rational design procedures. Questions still requiring answers are:

- What is the influence of velocity?
- What range of ice conditions might be experienced?
- What ice loads might arise in the most severe conditions?
- Is old ice a hazard?
- What type of extreme value distributions are valid?

The answers to these questions require the acquisition of considerably more data.

10. CONCLUSIONS

A system has been developed that can measure ice loads on fishing vessels, in particular, National Sea Products' 'CAPE BRIER'. The system represents an initial attempt in this area, and while certain problems were encountered, considerable understanding of ice loads on fishing vessels has been gained.

Data was collected during a period of seven days operating in ice. The highest single sub-panel pressure recorded was 644 kPa (area = .108m²). Ice pressures exceeded threshold levels during eighty-six five-minute sampling periods.

Statistical analysis of the ice pressures indicates that plate pressures tend to follow a Gumbel Type I extreme value distribution, while larger area pressures acting on the frames tend to follow Gumbel Type II distributions. Insufficient data exist to allow determination of rational design procedures. This is illustrated by the fact that, based on the present data, estimates of time between plate damage for the CAPE BRIER range from 1 to 100 weeks of operating in similar ice conditions.

11. RECOMMENDATIONS

The main recommendation is that the program for studying ice loads on fishing vessels continue. As key parts of the program the following items are recommended.

1. Longer term data collection, including dedicated testing.

2. A more detailed finite element model is required to better understand the shear in the webs of the frame. Only in this way can better agreement with the physical calibration be obtained.

3. Inclusive in 2., a more detailed analysis of the stringer, along with strain gauging of the stringer.

4. Extension of the instrumented area.

5. Examination of plate response both with finite element modelling and strain gauging.

6. Collection of more operational parameters to correlate with ice loads. These parameters should include ship speed, actual waterline position, ice conditions, ice properties and sea state.

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APPENDIX A

COMPUTATION OF MECHANICAL PROPERTIES OF SEA ICE

Recent studies and symposia (IAHR, 1981 and API, 1982) have recommended standard procedures for measuring ice properties in the Canadian Arctic. Until a uniform body of data becomes available, ice mechanical properties are best derived from "universal" or best-fit curves based on uniform or comparable test conditions rather than a particular geographic area.

Universal curves have been derived from sea ice crushing and flexural strengths. Data from Hirsohi, et al, (Figure 1) show that, at a given strain rate, crushing strength is temperature dependent. Hiroshi's data for first year ice at temperatures from -2 to -13°C can be used to estimate uniaxial crushing strength from mean monthly temperatures (Table 1). As shown in Figure 2 uniaxial crushing strength is strongly strain rate dependent, with three failure modes bounded by strain rates of approximately 5×10^{-3} and 10^{-2}. Strain rates used by Hiroshi fall in the transition range. Crushing strength in the brittle zone strain rate would be lower, possibly by as much as a factor of two, but there is insufficient experimental data in this range to provide measurements or estimates. The brittle range values are the most appropriate for ships transiting ice.

Flexural strength of first year ice measured from in situ cantilever beams, depicted in Figure 3 as a function of brine volume, is shown as:

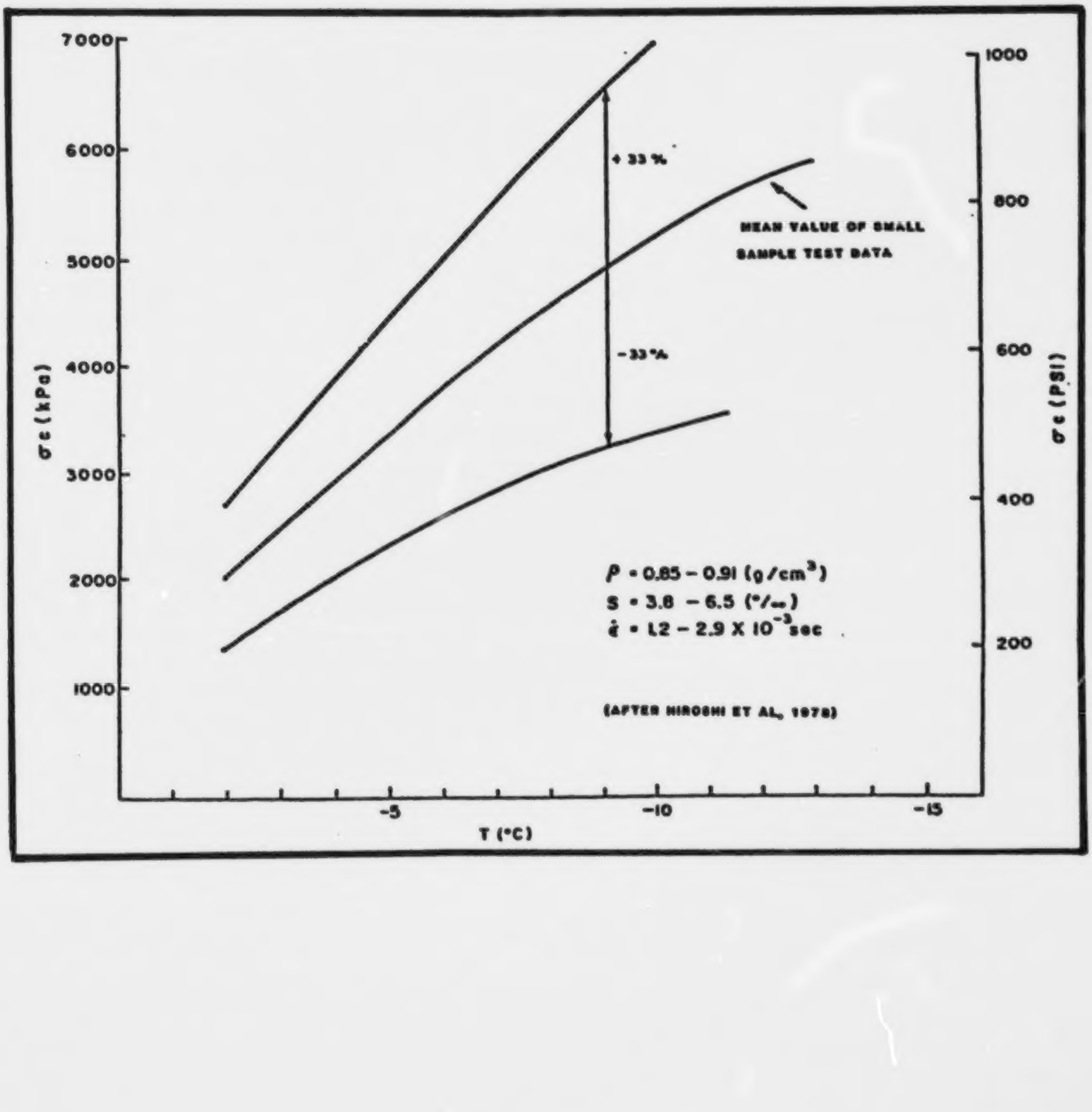
$$\sigma f = 850\ (1 - 0.072\sqrt{V_b})\ \text{for}\ \sqrt{V_b} < 11.1$$

where:

σf = ice flexural strength in kPa
V_b = ice brine volume in ppt.

FIGURE 1

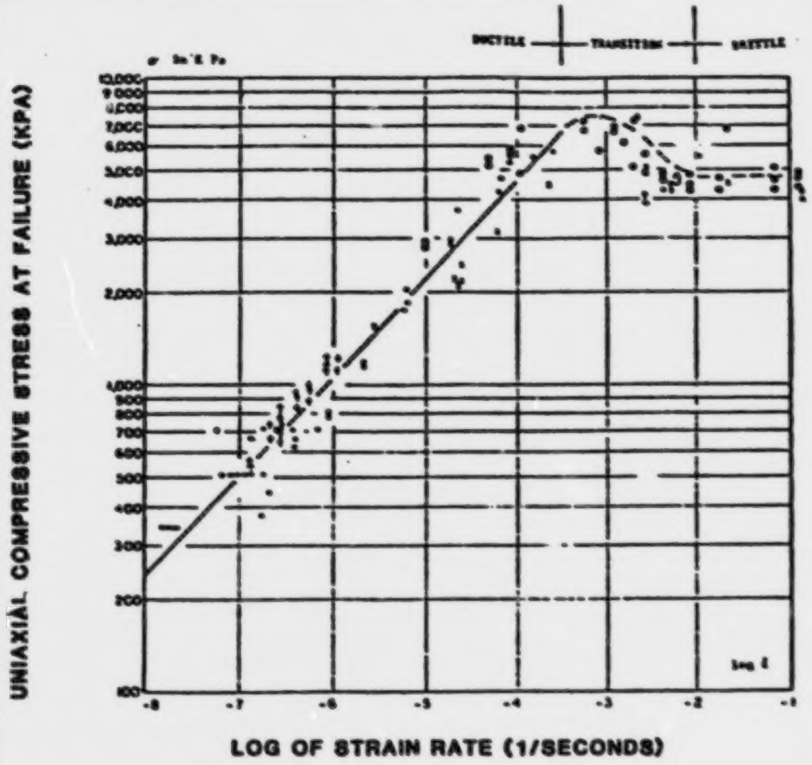
INFLUENCE OF TEMPERATURE ON UNIAXIAL CRUSHING STRENGTH OF SEA ICE



(AFTER HIROSHI ET AL, 1978)

FIGURE 2

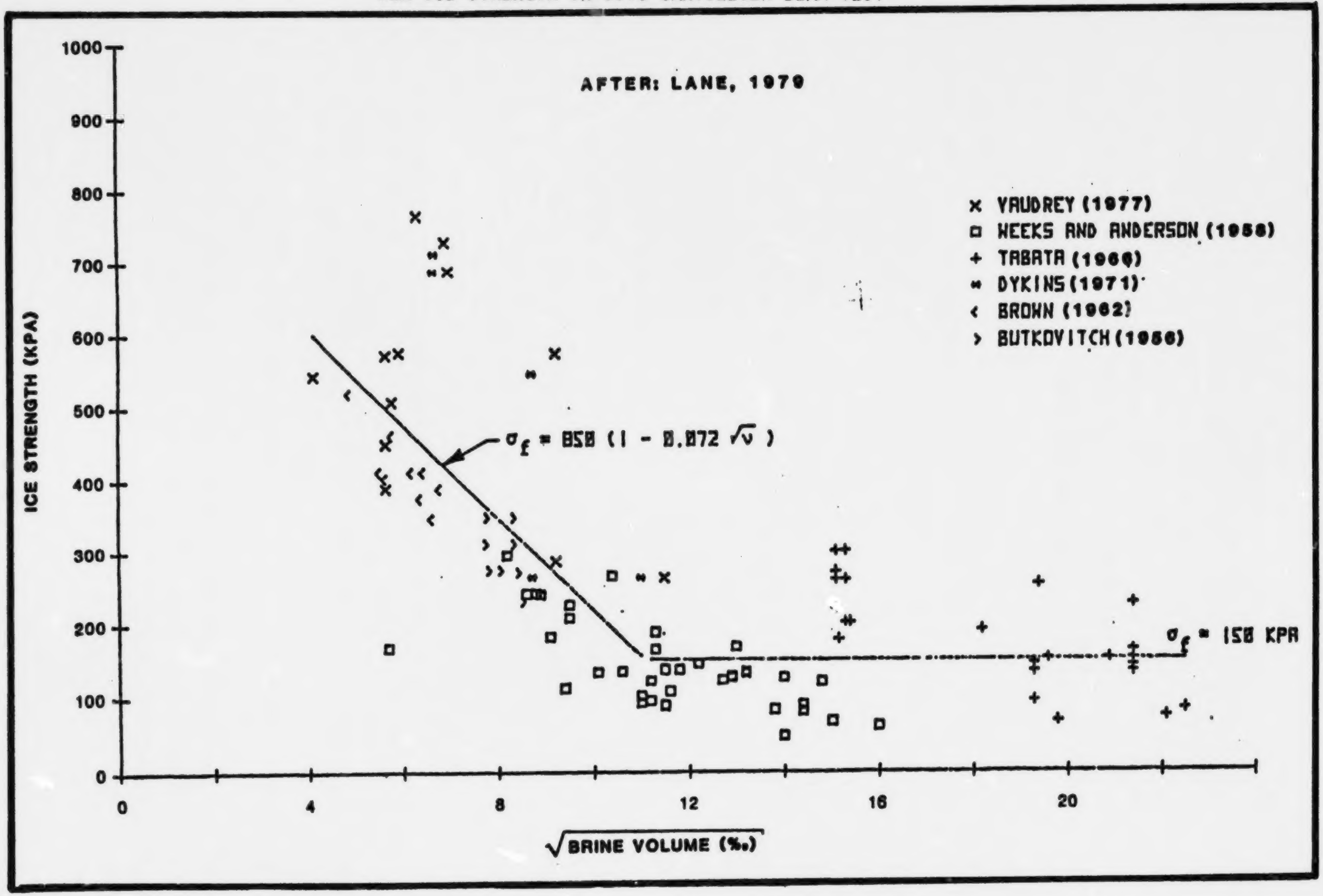
UNIVERSAL CURVE FOR UNIAXIAL COMPRESSIVE STRENGTH
OF S2 ICE AT -10°C



AFTER MICHEL AND TOUSSAINT (1977)

FIGURE 3

SEA ICE STRENGTH IN-SITU CANTILEVER BEAM TEST



Brine volume at a particular location is dependent upon ice age and temperature history, but can be calculated from temperature and salinity (Frankenstein and Garner, 1967) as:

$$V_b = S\ (0.532 - \frac{49.185}{\theta}$$

where:

V_b = brine volume in same units as S
S = ice salinity
θ = ice temperature in °C.

for $-0.5° < \theta < -22.9°$

The following assumptions are made:

1) Salinity of FY ice = 5 ppt.

2) Salinity of MY ice = 1 ppt.

3) Ice thickness from nearest shore station (AES, 1982).

4) Ice Temperature = $\frac{\text{mean air temp + water temp}}{2}$

5) Water temperature = -1.8°C.

6) No snow cover.

The presence of snow cover will tend to insulate the ice from low air temperatures and therefore the values presented here should be considered conservative.

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APPENDIX B

ENVIRONMENTAL LOG SHEETS

ICE ON SENSOR PANEL - TEST

TIME ATLANTIC	POSITION LAT.N LONG.N	HEADING	SPEED	ICE COVER	(CAKE) FLOE	THICKNESS	COMMENTS PHOTOS
10:36	S202				2-3m		Roll 7
20/03/84	S715	315°	4.0	10/10	dia.	1/2 m	29-36
11:00	S204				1-3m	1/4 m	Roll 8
20/03/84	S116	344°	4.0	9/10	3 nw	1-2 m	3-36
13:10	S214				1-3gr	1/4-3/4	
20/03/84	S126	327°	8.0	8/10	3-5nw	3/4-2 m	
15:20	S227				1-4gr	1/4-3/4	
20/03/84	S140	331°	8.0	9/10	2-4nw	1/2- 1 1/2	

M.V. CAPE BRIER ICEBERG LOG

DATE	TIME		SHIP POSITION		BEARING	RANGE	HEIGHT	DIAMETER	PHOTO #	COMMENTS
	hr	min	lat	long						
03/18/84	12	37	4833	5003	(1) ≃310°	4½ miles	≃60 ft.	70 ft.	12 & 13	Range obtained from radar
03/18/84	12	40	4833	5003	(2) ≃120°	2½ miles	≃30 ft.	60 ft.	14 & 15	Range obtained from radar
	13	55	4831	5014	(3) ≃275°	30 miles	≃10 ft.	30 ft.	17	Visual estimates
	13	55	4831	5014	(4) ≃ 90°	30 miles	≃15 ft.	30 ft.	18, 19	Visual estimates
03/19/84	06	07	5157	5055	(5) 35°	2 miles	≃150ft.	200 ft.	25-30, Roll #1	Bearing from ship
	06	32	5136	5006	(6) 18° from ship	3½ miles	30-40 ft.	60-70 ft.	30-32 Roll #1	
	08	05	5139	5021	(7) 48°	4¾ miles	150ft.	200 ft.	33 & 34 + 8	-10 on Roll# 2
03/20/84	06	22	5150	5102	(8) 280°	7½ miles				Difficult to estimate probably Medium size
	07	35	5154	5105	(9) 50°	5¼ miles	≃150ft.	≃200 ft.	22-24 Roll #6	
	09	37	5159	5150	(10) 280°	4¼ miles	≃50 ft.	≃200 ft.		Difficult to estimate
	09	45	5159	5110	(11) 15°	3½ miles	45 ft	75-80 ft.	14(50mm) 16	(135mm)
	09	45	5159	5110	(12) 340°	3½ miles	30 ft.	50 ft.	15(50mm)17,	18,19(135mm)
	09	53	5159	5110	(13) 75°	5 miles	MEDIUM SIZE	(≃75 ft. high)		Too far to estimate
	12	22	5210	5122	(14) 325°	2¼ miles	50 ft.	300 ft.	7 & 8	Roll# 9 (135mm)
	12	55	5213	5126	(15) 321°	3 miles	150 ft.	300 ft.	18 & 19	
	13	00	5214	5126	(16) 320°	11 miles	Too far to guess		20 & 21	Looked very large
	13	25	5215	5129	(17) 268°	5½ miles	Too far to tell			Medium sized
	14	02	5219	5133	(18) 110°	3½ miles	50 ft.	75 ft.	9	Roll # 10
	14	20	5221	5135	(19) 300°	3½ miles	100 ft.	1000 ft.	10 & 11	
	14	20	5221	5135	(20) 150°	5 miles	MEDIUM SIZE			
	15	36	5228	5140	(21) 93°	7 miles	MEDIUM SIZE			
	15	36	5228	5140	(22) 98°	8 miles	MEDIUM SIZE			
	16	02	5231	5143	(23) 95°	<1 mile	30 ft.	100 ft.	0 & 1 1 & 2	Roll # 12
	16	08	5231	5144	(24) 10°	3 miles	MEDIUM SIZE			

M.V. CAPE BRIER ICEBERG LOG

DATE	TIME		SHIP POSITION		BEARING	RANGE	HEIGHT	DIAMETER	PHOTO #	COMMENTS
	hr	min	lat	long						
03/20/84	16	08	5231	5144	(25) 45°	3 miles	MEDIUM SIZE			
	16	10	5231	5144	(26) 315°	4 miles	Too far to guess			

M.V. CAPE BRIER ICEBERG LOG

DATE	TIME		SHIP POSITION		BEARING	RANGE	HEIGHT	DIAMETER	PHOTO #	COMMENTS
	hr	min	lat	long						
03/20/84	16	10	"	"	(27) 280°	4½	To far to guess			xMedium
	16	10	"	"	(28) 265°	3½	To far to guess			xMedium
03/21/84	5	50	5301	5209	(29) 120°	6 miles	Difficult to guess		Roll #12 14&15	=Very large
	7	20	5257	5202	(30) 300°	3½ miles	100 ft.	200 ft.	32, 33	
	7	40	5256	5203	(31) 220°	4½	To far to guess			
	7	40	5256	5203	(32) 205°	4½	To far to guess			
	8	02	5255	5204	(33) 100°	6½ miles	150 ft.	450 ft.		
	14	52	5228	5133	(34) 348°	5½ miles	150 ft.	250 ft.		
	16	10	5224	5129	(35) 320°	2½ miles	150 ft.	300 ft.		
03/24/84	15	05	5136	5017	(36) 52°	2 miles	75 ft.	500 ft.		
	15	10	5135	5015	(37) 50°	1½ miles	30 ft.	60 ft.		

M.V. CAPE BRIER ICEBERG LOG

DATE	TIME		SHIP POSITION		BEARING	RANGE	HEIGHT	DIAMETER	PHOTO #	COMMENTS
	hr	min	lat	long						
03/25/84	6	00	5001	5003	(39) 82°	4½	100 ft.	400 ft.	32, 33	Roll# 15
	6	15	4950	5004	(41) 290°	2 miles	30 ft.	70 ft.		
	6	20	4950	5004	(42) 315°	5 miles	Medium Sized			
	6	20	4950	5004	(43) 340°	5 miles	Medium Sized			
	6	55	4952	5008	(44) 85°	6 miles	Medium Sized			
	7	15	4949	5010	(45) 45°	1 mile	75 ft.	250 ft.	35	Roll# 15
	8	00	4943	5012	(46) 50°	4 miles	200 ft.	400 ft.	3 & 4	Roll# 16
	8	10	4942	5013	(47) 270°	1 mile	25 ft.	125 ft.		
	8	15	4941	5013	(48) 50°	1.5 mile	40 ft.	120 ft.	5	Roll# 16 HDG 200
	9	08	4934	5017	(49) 50°	1 mile	25 ft.	50 ft.	6	
	10	25	4927	5022	(50) 280°	3 miles	200 ft.	750 ft.	—	

M.V. CAPE BRIER ICEBERG LOG

TRIP# 2 DARLENE BOURNE

DATE	TIME		SHIP POSITION		BEARING	RANGE	HEIGHT	DIAMETER	PHOTO #	COMMENTS
	hr	min	lat	long						
May 26	15	10	490283	504701					32	
			490283	504701					33	
			490283	504701					34	
			490283	504701					35	Radar 12/2 range
						1 3/4			0	
						3 mile			1	
						1 3/4 mile			2	Starboard all starboard
						1 3/4 mile			3	Starboard, same ice berg
						1 3/4			4	Starboard
						12 miles 7 miles			5	Port
	15	38				1 3/4			6	Starboard
						1 3/4			7	Starboard
						1 3/4			8	Starboard
						1 3/4			9	Starboard
									10	Ship in tow
	17	12	485087	505727		7 miles			11	Port
						2 1/4 + 2 1/2			12	Close 1 berg high behind
						4 1/2			13	Further away
						1 1/2 1 3/4			14	Same as 12
						3 mile			15	Same as 13
									16	Same as 12 (from behind)
									17	Same as 13
						1 1/4			18	Same as 13

MV CAPE BRIER ENVIRONMENTAL OBSERVATION LOG

03/19/84

TIME		LOCATION		HDG	SPD	TEMP	PRE	VISI	WAVE		WIND		CONCENTRAT'N						THK	BERG		PHOTOGRAPH #			COMMENTS
hr	min	lat	long	deg	kts	°C	rsf	nmi	ht	hd	sp	hd	tl	nw	gr	gw	fy	my	m	vi	ra	fwd	rada	other	
6	15	51° 57'	50°,55'	305°	6.5	0	nil	6	0.1	-	1-3	nw	9/10		7/10		2/10		0.5	2	2	25 26			roll #1
6	50	51° 36'	50°,06'	300°	8.0	0	nil	6	0.1	-	1-3	nw	7/10						0.1	3	3				
7	15	51°37'	50° 11'	304°	12.0	0	nil	6	0.1	nw	3	nw	1/10		1/10				0.5	4		34			
7	45	51°39'	50° 21'	275°	8.0	0	nil	6	0.1	nw	3	nw	2/10	1/10	1/10				0.5	4		1-7			
8	10	51°39'	50° 22'	297°	12.0	0	nil	6	.1-.5	nw	3	nw	1/10	1/10					1-2m	2		13-14			roll #2
8	30	51°40'	50° 26'	301°	6.0	0	nil	6	0.1	nw	3	nw	7/10	2/10	5/10				1-2m	2		18-19			roll #2
9	30	51°44'	50° 33'	290°	9.0	4.0°	nil	6	0.1	nw	3	nw	5/10	1/10		4/10			0-1	1	1	24-31			roll #2
10	30	51°46'	50° 41'	315°	3.0	0	nil	6	0.1	nw	3	nw	8/10	2/10	6/10				0.51	2	2	1-12			roll #2
11	30	51°47'	50° 46'	310°	4.0	8.0°	nil	6	0.1	nw	3	nw	7/10	2/10	5/10				0.52	1	1	25-27			roll #3
12	30	51°49'	50° 48'	96°	6.0	-5°C	nil	6	0.1	nw	4	nw	2/10	1/10	1/10				0.51	0	0	1-10			
13	30	51°47'	50° 46'	316°	5.0	0	nil	6	.1-.5	nw	4	nw	7/10	4/10	1/10	2/10			0.52	0	0	18-26			roll #4
14	30	51°50'	50° 49'	327°	4.5	0	nil	6	.1-.5	nw	4	nw	7/10		5/10			2/10	0.51	0	0	27-36			
15	30	51°50'	50° 51'	145°	9.5	-4°C	light flurries	6	.1-.5	nw	4	nw	4/10	2/10	2/10				0.52	0	0	1-8			
16	30	51°51'	50° 50'	327°	4.5	0	nil	6	0.1	nw	4	nw	8/10	3/10	5/10				0.52	0	0	15-24			roll #5

MV CAPE BRIER ENVIRONMENTAL OBSERVATION LOG

03/20/84

TIME		LOCATION		HDG	SPD	TEMP	PRE	VISI	WAVE		WIND		CONCENTRAT'N						THK	BERG		PHOTOGRAPH #			COMMENTS
hr	min	lat	long	deg	kts	°C	rsf	nmi	ht	hd	sp	hd	tl	nw	gr	gw	fy	my	m	vi	ra	fwd	rada	other	
6	30	51°50'	51°02'	353°	4.5	-10	nil	6	.1-.5	nw	4	nw	9/10	3/10	5/10				¼-2	2	2	0-10			roll# 6
7	30	51°53'	51°05'	339°	4.0	-7	nil	6	—	—	4	nw	10/10	3/10	7/10				¼-2	4	4	11-21			
8	30	51°57'	51°04	316°	3.0	-10	nil	6	.1-.5	nw	4	nw	1/10		1/10				¼-½	6	6	25-33			
9	30	51°59'	51°10'	318°	4.0	0	nil	6	.1-.5	nw	4	nw	5/10	2/10	3/10				¼-1	6	6	5-13			roll# 7
10	30	52°02'	51°15'	297°	4.0	0	nil	6	—	—	4	nw	10/10	4/10	6/10				½-2	5		20-28			
11	30	VESSEL HAULING BACK NO MEASUREMENTS MADE									4														
12	30	52°11'	51°23'	302°	8.0	-4	nil	6	.1	nw	4	nw	8/10	2/10	6/10				¼-1½	6	6	9-17			roll# 9
13	30	52°16'	51°30'	334°	10.5	-4	nil	6	.1-.5	nw	4	nw	4/10	3/10	1/10				¼-2	7	7	0-7			roll# 10
14	30	52°22'	51°35'	330°	10.5	+3	nil	6	.1-.5	nw	4	nw	6/10	3/10	3/10				¼-2	7	7	12-20			
15	30	52°28'	51°40'	334°	6.5	0	nil	6	.1	nw	4	nw	8/10	2/10	6/10				¼-1½	6	6	1-9			roll# 11
16	30	52°33'	51°45'	348°	5.o	-7	nil	6	.1	nw	4	nw	7/10	5/10	2/10				¼-2	9	9	2-10			roll# 12

MV CAPE BRIER ENVIRONMENTAL OBSERVATION LOG

03/21/84

TIME		LOCATION		HDG	SPD	TEMP	PRE	VISI	WAVE		WIND		CONCENTRAT'N						THK	BERG		PHOTOGRAPH #			COMMENTS
hr	min	lat	long	deg	kts	°C	rsf	nmi	ht	hd	sp	hd	tl	nw	gr	gw	fy	my	m	vi	ra	fwd	rada	other	
6	30	52°59'	52°04'	130°	4.0	-7	nil	6	—	—	4	nw	9/10	5/10	4/10				½-2	3	3	18-26			Roll# 12
7	30	52°56'	52°03'	209°	2.6	-7	nil	6	—	—	4	nw	9/10	4/10	5/10				½-1½	5	5	34-135			Roll# 13 1-7
8	30	52°54'	52°04'	200°	3.5	-6		6	—	—	4	nw	8/10	4/10	4/10				½-1½	1	2	18-26			visibility dropping
9	30	52°50'	52°02'	139°	2.5	-4	snow	2-4	.1-.5	nw	4	nw	6/10	3/10	3/10				½-2	1	4	27-35			
10	30	52°47'	51°56'	135°	3.0	-2	snow	2-4	.1	sw	4	sw	7/10	3/10	4/10				½-1½	0	5	0-8			Roll# 14
11	30	52°44'	51°51'	180°	3.5	-2	snow	2-4	.1	sw	4	sw	7/10	3/10	4/10				½-1½	0	4	9-16	Hard to tell ice types		
12	30	52°41'	51°48'	186°	4.0	-1	snow	2-4	.1	sw	4	sw	7/10	3/10	4/10				½-1½	0	4	ice cover looks similar to above			
13	30	52°37'	51°43'	147°	4.5	+4	snow	2-4	.1	sw	4	sw	7/10	3/10	4/10				½-1½	0	6	17-26			
14	30	52°35'	51°35'	140°	12.5	+4°	rain	6	.1-.5	sw	4	sw	1/10	1/10					½-1	0	4				
15	30	52°31'	51°31'	196°	4.5	+3°	freezing rain	4-6	.1-.5	sw	4	sw	7/10	4/10	3/10				½-2	3	3	27-35			
16	30	52°21'	51°26'	140°	8.0	+5°	freezing rain	4-6	.1-.5	sw	4	sw	6/10	2/10	4/10				½-1½	3	3	0-8			

MV CAPE BRIER ENVIRONMENTAL OBSERVATION LOG

03/22/84

TIME		LOCATION		HDG	SPD	TEMP	PRE	VISI	WAVE		WIND		CONCENTRAT'N						THK	BERG		PHOTOGRAPH #			COMMENTS
hr	min	lat	long	deg	kts	°C	rsf	nmi	ht	hd	sp	hd	tl	nw	gr	gw	fy	my	m	vi	ra	fwd	rada	other	
11	30	51°55'	50°55'	325°	5.5	2°	nil	6	–	–	4	w	7/10	3/10	4/10				½-1½	0	0				
12	30	51°59'	50°59'	324°	1.5	2°	nil	6	–	–	4	w	7/10	3/10	4/10				½-1½	0	0				
13	30	51°59'	50°59'	25°	2.0	2°	nil	6	–	–	4	w	6/10	2/10	4/10				½-2	0	0				
14	30	51°57'	50°57'	144°	4.0	0°	nil	6	–	–	4	w	7/10	3/10	4/10				½-2	0	1				
15	30	51°54'	50°55'	190°	1.0	0°	nil	6	–	–	4	w	9/10	3/10	6/10				½-2	2	2				
16	30	51°56'	50°56'	339°	2.0	0°	nil	6	–	–	4	w	7/10	3/10	4/10				½-2	0	0				

MV CAPE BRIER ENVIRONMENTAL OBSERVATION LOG

03/23/84

TIME		LOCATION		HDG	SPD	TEMP	PRE	VISI	WAVE		WIND		CONCENTRAT'N						THK	BERG		PHOTOGRAPH #			COMMENTS
hr	min	lat	long	deg	kts	°C	rsf	nmi	ht	hd	sp	hd	tl	nw	gr	gw	fy	my	m	vi	ra	fwd	rada	other	
6	30	5155	5057	46°	2	0°	nil	4-6	.1	SE	3	W	7/10	3/10	4/10				½-2	0	3				
7	30	5155	5055	150°	4	0°	fog	1-2	.1	SE	3	SE	5/10	2/10	3/10				½-2	0	1				
8	30	5156	5056	330°	4.5	+2°	fog	½	.1	SE	4	SE	4/10	1/10	3/10				½-2	0	0				Towing
9	30	5159	5059	342°	3.5	+2°	fog	½	.1	SE	4	SE	6/10	2/10	4/10				½-2	0	0				Hauling back
10	30	5200	5059	33°	0.5	+2°	fog	½	.1	SE	4	SE	6/10	2/10	4/10				½-2	0	0				Boat station
11	30	5200	5059	41°	0	+2°	rain	6	.1-.5	SE	4	SE	3/10	1/10	2/10				½-2	0	0				Boat station
12	30	5200	5059	275°	0	+2°	rain	6	.1-.5	SE	4	SE	4/10	1/10	3/10				½-2	0	0				Boat station
13	30	5200	5059	280°	0	+2°	nil	6	.1-.5	SE	4	SE	4/10	1.5/10	2.5/10				½-2	0	0				Boat station
14	30	5159	5059	10°	1.5	+2°	mild rain	6	.1-.5	SE	4	SE	8/10	3/10	5/10				½-2	0	0				Reading to Tow
15	30	5159	5059	210°	6.5	+2°	mild rain	6	.1	SE	4	SE	6/10	3/10	3/10				½-2	0	0				Launching Nets
16	30	5156	5056	160°	4.0	+3°	nil	10	0	—	4	SE	9/10	4/10	5/10				½-2	0	0				Towing

MV CAPE BRIER ENVIRONMENTAL OBSERVATION LOG

03/24/84

TIME		LOCATION		HDG	SPD	TEMP	PRE	VISI	WAVE		WIND		CONCENTRAT'N						THK	BERG		PHOTOGRAPH #			COMMENTS
hr	min	lat	long	deg	kts	°C	rsf	nmi	ht	hd	sp	hd	tl	nw	gr	gw	fy	my	m	vi	ra	fwd	rada	other	
7	30	5158	5051	279°	5.0	0°	fog	< 1	—	—	3	SE	6/10	2/10	4/10				½-2	0	0				Towing
8	30	5200	5056	328°	0.5	2°	fog	< 1	—	—	3	SE	7/10	3/10	4/10				½-2	0	0				Haulingback
9	30	5158	5054	129°	4.5	1°	fog lifting	1.25	—	—	3	SE	6/10	3/10	3/10				½-2	0	0				Towing
10	30	5156	5048	125°	11.0	1°	fog light	≈ 1	.1	SE	3	SE	5/10	2/10	3/10				½-2	0	0				Steaming home
11	30	5153	5041	140°	3.5	3°	fog	~ 1	—	—	3	SE	8/10	3/10	5/10				½-2	0	0				Steaming home
12	30	5149	5036	180°	8	2	fog lifting	~1.5	.1	SE	3	SE	5/10	2/10	3/10				½-2	0	0				Steaming home
13	30	5144	5021	140°	4	2	heavy fog	0	—	—	3	SE	9/10	2/10	7/10				½-2	0	0				Steaming home
14	30	5140	5021	135°	6	2	rain	4	.1-.5	SE	3	SE	6/10	2/10	4/10				½-2	0	0				Steaming home
15	30	5134	5013	140°	4	2	—	6	—	—	3	SE	9/10	2/10	7/10				½-2	2	2				Steaming home
15	30	5125	5005		6	1	fog	< 1	.1	SE	3	SE	4/10	3/10	1/10				½-2	0	0				Steaming home

MV CAPE BRIER ENVIRONMENTAL OBSERVATION LOG

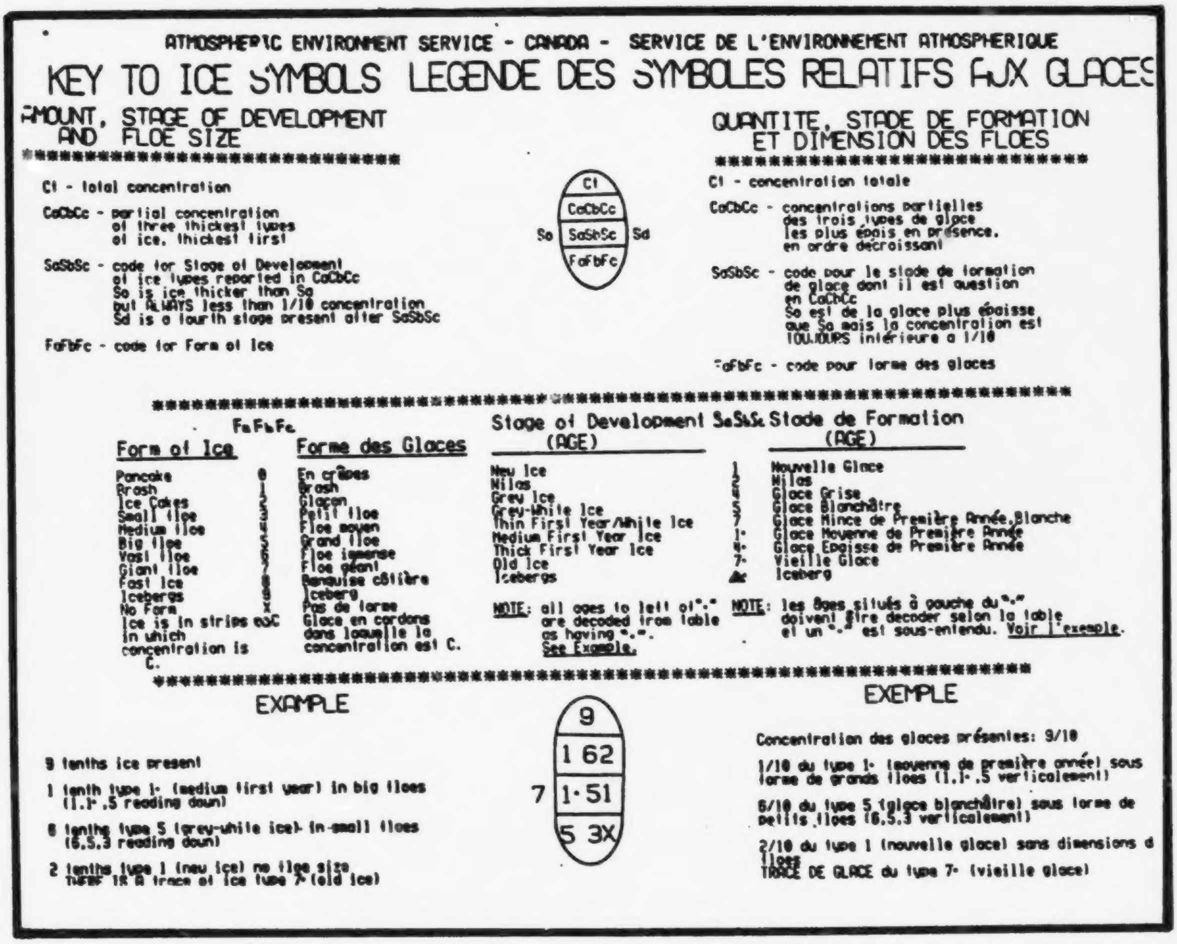
03/25/84

TIME		LOCATION		HDG	SPD	TEMP	PRE	VISI	WAVE		WIND		CONCENTRAT'N						THK	BERG		PHOTOGRAPH #			COMMENTS
hr	min	lat$_N$	long$_W$	deg	kts	°C	rsf	nmi	ht	hd	sp	hd	tl	nw	gr	gw	fy	my	m	vi	ra	fwd	rada	other	
6	30	4958	5006	185°	12.5	7	—	6	.1-.5	5	3	SE	6/10	4/10	2/10				½-2	4	4				Steaming home
7	30	4947	5011	209°	7.0	13	—	6	—	—	3	SE	9/10	6/10	3/10				½-2	2	4				Steaming home
8	30	4939	5014	196°	7.0	7	—	6	.1-.5	5	3	SW	6/10	4/10	2/10				½-2	6	6				
9	30	4931	5019	210°	8	5	—	6	—	—	3	SW	9/10	6/10	3/10				½-2	1	1				Steaming home
10	30	4927	5023	210°	4 3/4	4	—	3	—	—	3	SW	8/10	3/10	5/10				½-2	1	1			See photo 7-18 on roll 16	for thicknes
11	30	4923	5026	250°	6.0	4	—	3	—	—	3	SW	9/10	4/10	5/10				½-2	0	0				
12	30	4918	5032	220°	7	5	—	6	—	—	3	SW	9/10	6/10	3/10				½-2	0	0				
13	30	4915	5040	270°	9	3	—	6	—	—	3	SW	7/10	4/10	3/10				½-2	0	0				Ice starting to clear
14	00	4914	5047	235°	12.5	2	—	6	0.5-1.25	5	3	SW	1/10	.5/10	.5/10				½-2	0	0				Open water last entry

APPENDIX C

KEY TO AES CHARTS

KEY TO A.E.S. "EGG" CODE



ATMOSPHERIC ENVIRONMENT SERVICE - CANADA - SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE

KEY TO ICE SYMBOLS LEGENDE DES SYMBOLES RELATIFS AUX GLACES

AMOUNT, STAGE OF DEVELOPMENT AND FLOE SIZE

Ct - total concentration

CaCbCc - partial concentration of three thickest types of ice, thickest first

SaSbSc - code for Stage of Development of ice types reported in CaCbCc
So is ice thicker than Sa but ALWAYS less than 1/10 concentration
Sd is a fourth stage present after SaSbSc

FaFbFc - code for Form of Ice

QUANTITE, STADE DE FORMATION ET DIMENSION DES FLOES

Ct - concentration totale

CaCbCc - concentrations partielles des trois types de glace les plus épais en présence, en ordre décroissant

SaSbSc - code pour le stade de formation de glace dont il est question en CaCbCc
So est de la glace plus épaisse que Sa mais la concentration est TOUJOURS inférieure à 1/10

FaFbFc - code pour forme des glaces

Form of Ice	FaFbFc	Forme des Glaces
Pancake	0	En crêpes
Brash	1	Brash
Ice Cakes	2	Glaçon
Small floe	3	Petit floe
Medium floe	4	Floe moyen
Big floe	5	Grand floe
Vast floe	6	Floe immense
Giant floe	7	Floe géant
Fast Ice	8	Banquise côtière
Icebergs	9	Iceberg
No Form	X	Pas de forme
Ice is in strips in which concentration is C.	ωC	Glace en cordons dans laquelle la concentration est C.

Stage of Development (AGE)	SaSbSc	Stade de Formation (AGE)
New Ice	1	Nouvelle Glace
Nilas	2	Nilas
Grey Ice	4	Glace Grise
Grey-White Ice	5	Glace Blanchâtre
Thin First Year/White Ice	7	Glace Mince de Première Année,Blanche
Medium First Year Ice	1·	Glace Moyenne de Première Année
Thick First Year Ice	4·	Glace Epaisse de Première Année
Old Ice	7·	Vieille Glace
Icebergs	▲	Iceberg

__NOTE__: all ages to left of "·" are decoded from table as having "·". __See Example.__

__NOTE__: les âges situés à gauche du "·" doivent être decoder selon la table et un "·" est sous-entendu. __Voir l'exemple.__

EXAMPLE

9 tenths ice present

1 tenth type 1· (medium first year) in big floes (1,1·,5 reading down)

6 tenths type 5 (grey-white ice) in small floes (6,5,3 reading down)

2 tenths type 1 (new ice) no floe size
THERE IS A trace of ice type 7· (old ice)

EXEMPLE

Concentration des glaces présentes: 9/10

1/10 du type 1· (moyenne de première année) sous forme de grands floes (1,1·,5 verticalement)

6/10 du type 5 (glace blanchâtre) sous forme de petits floes (6,5,3 verticalement)

2/10 du type 1 (nouvelle glace) sans dimensions d floes
TRACE DE GLACE du type 7· (vieille glace)

APPENDIX D

DERIVATION OF BEAM SHEAR FORCE FROM STRAIN GAUGE RESPONSE

D. DERIVATION OF BEAM SHEAR FORCE FROM STRAIN GAUGE RESPONSE

It is well known that the state of stress at locations on the surface of a material can be determined from the electrical response of strain gauge rosettes mounted at the points of interest. In essence, strategic orientation of strain gauges about a point allows for determination of the principal strains (and hence principal stresses). Once the principal stresses are known, the 2-D state of stress on any plane (e.g. the transverse cross-section of a beam) can be calculated using a method such as Mohr's "circle of stress".

In general, the 2-D state of stress in a differential element of a material is a function of three quantities, namely the orientation and the magnitudes of the two principal stresses. If all three are unknown then at least three gauges are required in a rosette to determine the complete state of stress. In the case of points along the neutral axis of a beam where the principal stresses are known to be oriented at 45° to the neutral axis, a two gauge, 90° rosette will suffice. In the present case these two gauge rosettes were mounted along the neutral axes of the frames in the hull panel of interest. A typical rosette is shown in Figure D.1. From the theory of elasticity, the general 2-D state of stress is a material with principal planes p and q (see Figure D.1) is given by:

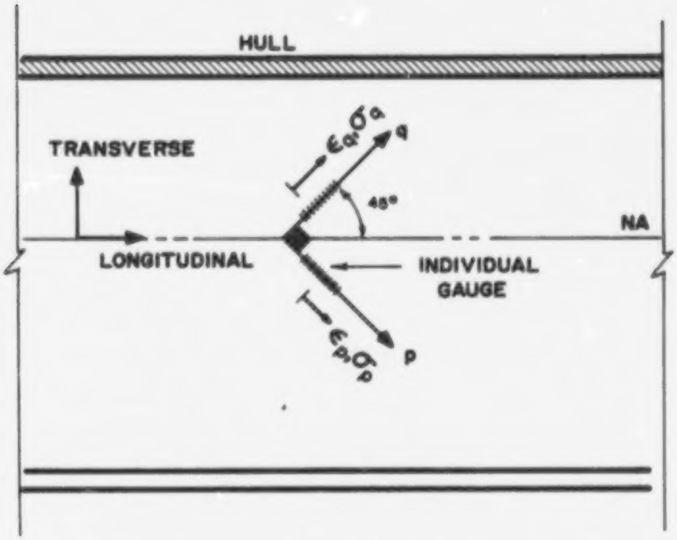
$$\sigma p = \frac{E}{1-\nu^2}(\varepsilon p + \nu\varepsilon q)$$

$$\sigma q = \frac{E}{1-\nu^2}(\varepsilon q + \nu\varepsilon p) \qquad (D.1)$$

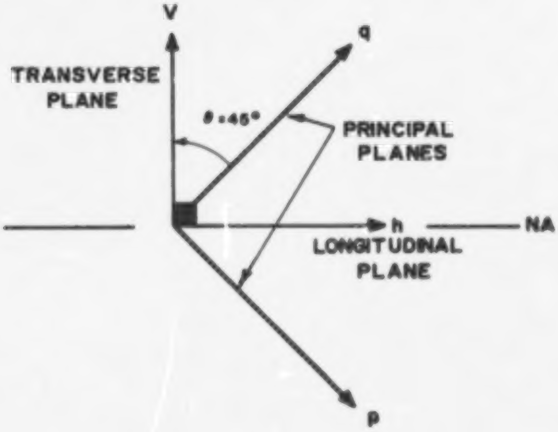
$$(\ pq) = 0$$

FIGURE D.1

a) TYPICAL STRAIN GAUGE ROSETTE
- LOCATION and ORIENTATION


HULL
TRANSVERSE
LONGITUDINAL
ϵ_q, σ_q
q
45°
NA
INDIVIDUAL GAUGE
ϵ_p, σ_p
p

b) ORIENTATION of the PRINCIPAL PLANES WITH RESPECT to the TRANSVERSE and LONGITUDINAL PLANES of the FRAME


V
q
TRANSVERSE PLANE
θ=45°
PRINCIPAL PLANES
h
NA
LONGITUDINAL PLANE
p

where $\sigma p, \sigma q$ are the principal stresses,
E is the Young's modulus (200,000 MPa) and
ν is the Poisson ratio (0.3) of steel and

$\epsilon p, \epsilon q$ are the principal strains. From the theory of 2-D transformation of stress the magnitude of the transverse shear stress, $_{hv}$ (see Figure D.1) is given by:

$$| \ _{hv}| = | - \frac{\sigma p - \sigma q}{2} \sin (2 \times 45^\circ) + \ _{pq} \cos (2 \times 45^\circ)| \qquad (D.2)$$

Hence $$| \ _{hv}| = | (\frac{\sigma p - \sigma q}{2}) | \qquad (D.3)$$

For practical reasons (e.g. the elimination of electrical noise) it was decided that the basic measurement in this case would be the difference, $\epsilon p - \epsilon q$, exhibited by the gauges in a rosette. By subtracting the second of equations (D.1) from the first one can derive

$$| \ _{hv}| = | \frac{E}{2 (1 + \nu)} (\epsilon p - \epsilon q)| \qquad (D.4)$$

Hence with rosettes placed as discussed above, the transverse shear stress along the neutral axes of the frames can be determined.

The cross section of a typical frame is depicted schematically in Figure D.2. Since the frame is continuously welded to the hull, the hull effectively forms an outer flange to the frame. For the calculation of the neutral axis (NA), of the frame, this effective outer flange width, b_h, is taken as the frame spacing, 300 mm. Since the web of the frame is thin walled, the transverse shear stresses in the web may be assumed constnt across the thickness. Hence the familiar formula for shear stresses in beams may be applied, namely,

$$(y_1) = \frac{Q\ (y_1)}{It} \qquad (D.5)$$

where (y_1) is the vertical shear stress at distance y, from the N.A.

I is the moment of inertia of the section about the N.A.

t is the web thickness

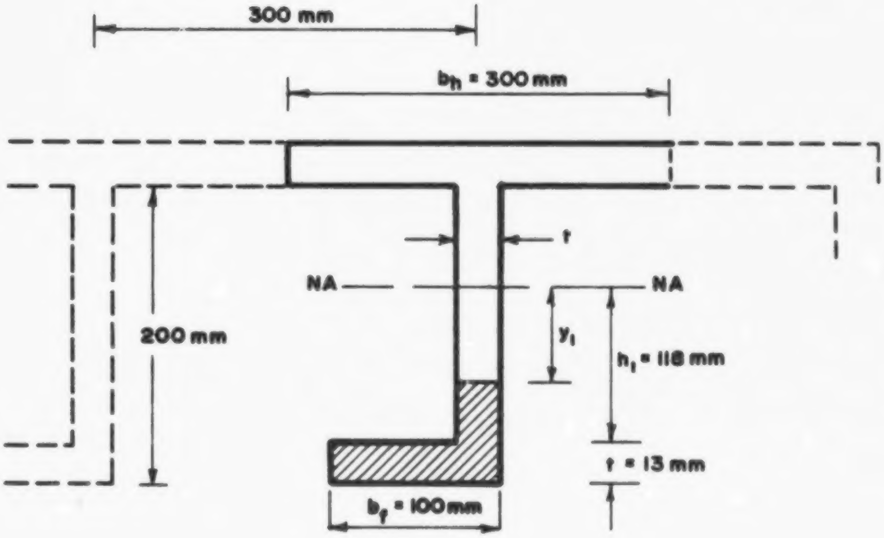
V is the transverse shear force

and $Q(y_1)$ is the first statical moment of the shaded area (in Figure D.2) about the N.A. In the present case it can be shown that:

$$Q(y_1) = h_1 t\ b_f + \tfrac{1}{2}\ b_f t^2 + \tfrac{1}{2}\ t\ h_1^2 - \tfrac{1}{2}\ t\ y_1^2 \qquad (D.6)$$

FIGURE D.2

EFFECTIVE CROSS SECTION of a TYPICAL INSTRUMENTED FRAME

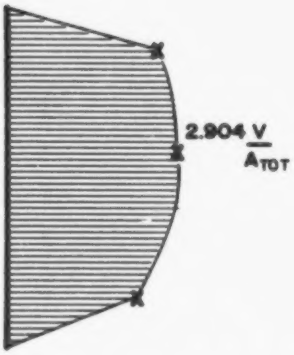

300 mm
b_h = 300 mm
t
NA
NA
200 mm
y_1
h_1 = 118 mm
t = 13 mm
b_f = 100mm

I_{NA} = 4.517 X 10^7 mm^4

A_{AT} = 6730 mm^2

FIGURE D.3

DISTRIBUTION of TRANSVERSE SHEAR STRESS


$2.904 \frac{V}{A_{TOT}}$

Substitution of this equation into the previous one reveals that the distribution of traverse shearing stresses is parabolic with the maximum occuring at the N.A. This distribution is graphically shown in Figure D.3 with the value at the N.A. noted as a function of (V/A_T), where A_T is the "effective" cross sectional area of the frame, including the outer flange formed by the hull. Hence we have the connection between transverse shear stresses and shear force. Rearranging equation (D.5) and substituting equation (D.4) into the result, one can derive

$$V = \frac{It}{Q_{NA}} \tag{D.7}$$

$$= \pm \frac{It}{Q_{NA}} \frac{E}{2(1 + \nu)} (\varepsilon p - \varepsilon q)$$

or

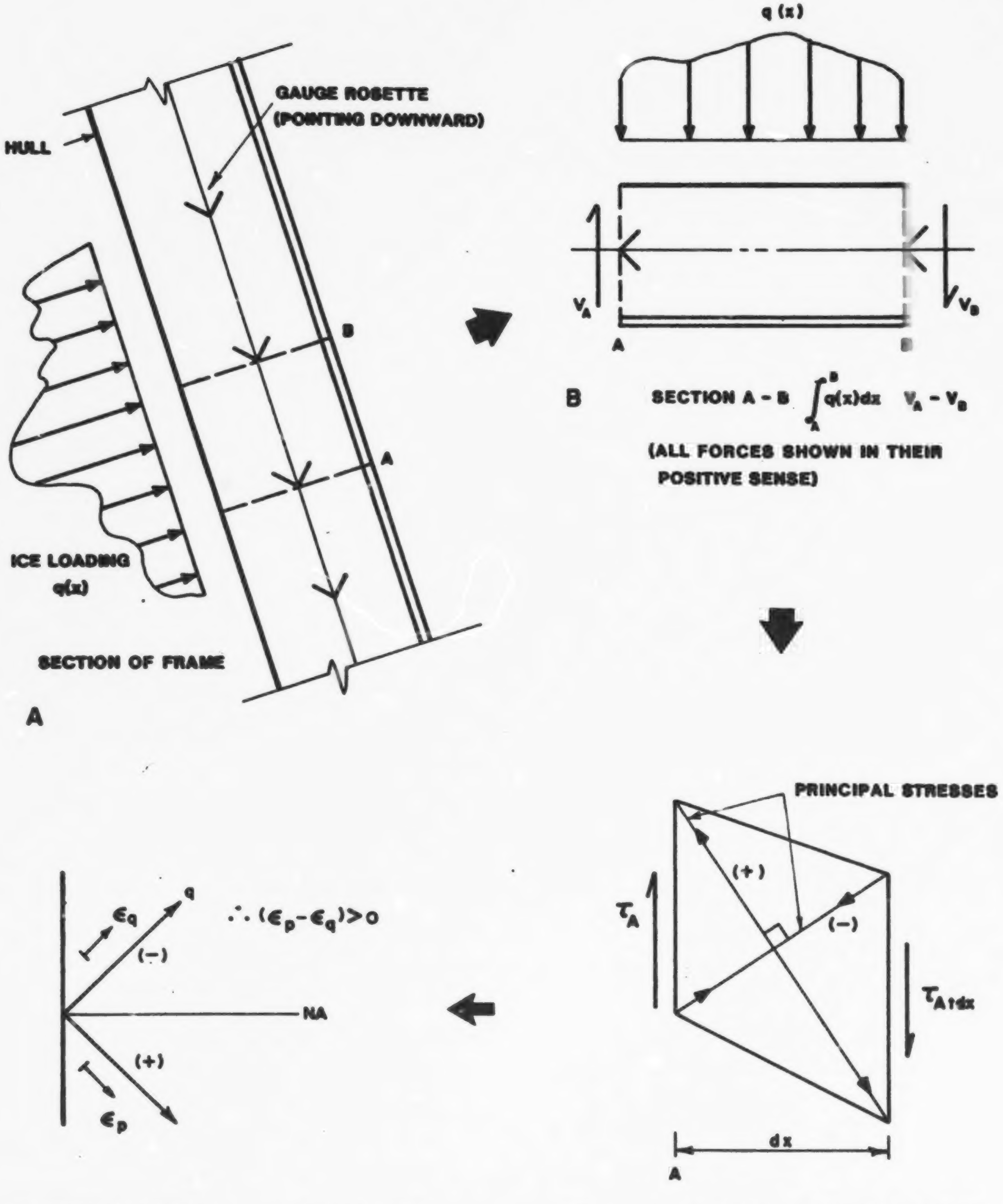
$$V = \pm \text{ "factor" times "measurement"}$$

where "factor" is a function of the elastic and geometric properties of the frame section. Since these are assumed in the analysis, "factor" may need to be corrected based on the results of the physical calibration of the system.

At this point it is necessary to establish a sign convention for transverse shear force. This is best done with the aid of a series of diagrams as illustrated in Figure D.4. The sense of "positive" shear is indicated in diagrams B and C and corresponds to the "Designer's sign convention" often used by Civil Engineers in North America.

Thus if hull loading is taken as "inward positive" (i.e. ice pressure is positive), then a frame loaded between two gauge locations will produce a positive measurement (i.e. $\epsilon p - \epsilon q$) at the lower location and a negative measurement at the upper location. Hence the sense of shear force V in equation (D.1) is taken to be the sense of the measurement $\epsilon p - \epsilon q$.

DEFINITION of POSITIVE MEASUREMENT and SHEAR FORCE


q (x)
GAUGE ROSETTE
(POINTING DOWNWARD)
HULL
B
A
ICE LOADING
q(x)
V_A
V_B
A
B
PRINCIPAL STRESSES
(+)
(−)
τ_A
τ_{A+dx}
dx
A
ϵ_q
q
(−)
$\therefore (\epsilon_p - \epsilon_q) > 0$
NA
(+)
ϵ_p

A SECTION OF FRAME

B SECTION A - B $\int_A^B q(x)dx$ $V_A - V_B$

(ALL FORCES SHOWN IN THEIR POSITIVE SENSE)

D POSITIVE PRINCIPAL STRAIN DIFFERENCE (ie "MEASUREMENT")

C DIFFERENTIAL ELEMENT AT NA AT SECTION A IN POSITIVE SHEAR

APPENDIX E

DERIVATION OF MATRICES [T] AND [T_1]

DERIVATION OF MATRICES [T] and [T_1]

Recalling Section 6.2 in the text, these matrices were developed from results of applying "unit" loads (100 kn applied as a uniform pressure) to individual influence sub-panels in the Finite Element model.

From the results of the six "unit" influence loadings a 6x6 matrix of along frame shear differences may be constructed:

$$A = [a_{ij}]_{6x6} \qquad i, j = 25, 26, 27, 28, 29, 30$$

where a_{ij} = the shear difference across influence area i due to a "unit" load over influence area j

A second 6x6 matrix of adjacent frame shear differences may also be constructed:

$$B = [b_{ij}] \qquad \begin{array}{l} i = 19, 20, 21, 22, 23, 24 \\ j = 25, 26, 27, 28, 29, 30 \end{array}$$

where b_{ij} is defined similarly to a_{ij} above. The difference is that the influence areas "i" are situated on the adjacent frame. By applying the assumption of similarity of frames, a 30x30 matrix, V_u, of influence shear differences over the entire panel may be generated as indicated in the following:

$$V_u = \overline{V}_{ij} = \begin{bmatrix} [A] & [B] & 0 & 0 & 0 \\ [B] & [A] & [B] & 0 & 0 \\ 0 & [B] & [A] & [B] & 0 \\ 0 & 0 & [B] & [A] & [B] \\ 0 & 0 & 0 & B & [A] \end{bmatrix}$$

a portion of the matrix actually modelled.

where $\overline{V}_{ij}$ is defined similar to a_{ij}, and 0 is the 6 x 6 null matrix.

Similar to the development of the influence shear differences matrix $[V\ ]$, a matrix of influence stringer reactions can be developed. Two 6x6 matrices of along frame and adjacent frame influence stringer reactions, [C] and [D] respectively may be constructed such that:

$[C] = [C_{ij}]_{6x6}$ $\qquad$ $i, j = 25$ to 30

and $[D] = [d_{ij}]_{6x6}$ $\qquad$ $i = 19$ to 24

$j = 25$ to 30

where c_{ij}, d_{ij} = the stringer reaction at influence area i due to a "unit" load applied over area j.

It may be noted that only the fourth rows of C and D, (corresponding to sub-panels i = 28 and 22 respectively) are non-zero. Again applying the assumption of similarity of frames a 30 x 30 matrix, R_u, of influence stringer reactions can be generated.

$$R_u = [R_{ij}] = \begin{bmatrix} [C] & [D] & 0 & 0 & 0 \\ [D] & [C] & [D] & 0 & 0 \\ 0 & [D] & [C] & [D] & 0 \\ 0 & 0 & [D] & [C] & \boxed{[D]} \\ 0 & 0 & 0 & [D] & \boxed{[C]} \end{bmatrix}$$

portion of the matrix
actually modelled.

where R_{ij} is defined similarly to c_{ij} and d_{ij} and again 0 is the 6x6 null matrix.

Recalling equation 6.2, matrices R_u and V_u are related by:

$$[R_u] = [T_1]\,[V_u] \qquad \text{(E.1)}$$

and hence the matrix $[T_1]$ must be given by

$$[T_1] = [R_u]\,[V_u]^{-1} \qquad \text{(E.2)}$$

Recalling equation 6.1, we must have

$$P_u\ [I] = [T]\ ([V_u] - [R_u]) \qquad (E.3)$$

where P_u is the "unit" load (in this case 100 kn applied as a uniform pressure) and [I] is the 30 x 30 identity matrix. Therefore matrix [T] is given by:

$$[T] = P_u[I]\ ([V_u] - [R_u])^{-1} \qquad (E.4)$$

In the present case matrix $[T_1]$ was found to be fairly diagonal with non-zero rows only at rows 4, 10, 16, 22 and 28 and matrix [T] was highly diagonal, as predicted earlier. The sub matrices [A], [B], [C], and [D] derived from Finite Element model are given by:

[A]

along frame
shear
differences

(kN)

$$\begin{bmatrix} 77.320 & -.010 & -.250 & -.033 & .087 & .098 \\ -.620 & 77.270 & -.590 & -.255 & .290 & .353 \\ -1.050 & -1.390 & 74.970 & .175 & .528 & .600 \\ -20.189 & -42.130 & -59.710 & 2.856 & -54.540 & -39.300 \\ -.479 & -1.200 & -2.573 & .130 & 67.930 & -3.010 \\ .288 & .472 & .422 & .043 & -.420 & 78.340 \end{bmatrix}$$

[B]

adjacent
frame
shear
differences

(kN)

$$\begin{bmatrix} 11.204 & .708 & -1.79 & .054 & .051 & .055 \\ -.072 & 12.320 & 1.000 & -.043 & -.031 & -.015 \\ -.073 & -.450 & 11.070 & .729 & .139 & .148 \\ -3.193 & -5.875 & -8.319 & .281 & -7.224 & -10.050 \\ -.032 & -.426 & -.486 & -.051 & 8.254 & 1.487 \\ .116 & -.053 & -.014 & -.028 & -.778 & 10.630 \end{bmatrix}$$

[C]

along frame
stringer
reaction to
influence
loads

(kN)

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -20.19 & -42.31 & -59.71 & -28.76 & -53.17 & -38.66 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

[D]

adjacent
frame
stringer
reaction
to influence
loads

(kN)

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -2.591 & -5.876 & -8.319 & -4.222 & -6.825 & -10.0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

APPENDIX F

RESULTS OF THE PHYSICAL CALIBRATION

RESULTS OF THE PHYSICAL CALIBRATION

As described in the text (Section 7), the instrumented panel was loaded at six locations (sub-panels 2, 6, 14, 17, 26, 29) with tensile loads of 1 ton (9.8 KN), 3 ton (29 KN), and 4.5 ton (44 KN). These are labelled as readings 1 to 18 in the following pages. The particulars for each case are summarized in Table F.1. Each of the readings is formatted exactly as Figures 7.5 and 7.6 in the text and in each case the loaded location is identified with a box. In general there is good agreement of loads predicted for corresponding sub-panels below the stringer (sub-panels 26, 14, and 2) indicating a strong similarity of frames as was assumed in the analysis. Agreement among the corresponding sub-panels above the stringer was not so good. This is due at least in part to faulty gauges in this region, which were averaged out for the subsequent data analysis.

TABLE F.1

KEY TO THE NUMBERING OF THE PHYSICAL CALIBRATION READINGS

SUB-PANEL OF CALIBRATION POINT	LOADS 1 TON	 3 TONS	 4.5 TONS
26	1	2	3
29	4	5	6
17	7	8	9
14	10	11	12
2	13	14	15
6	16	17	18

```
CURRENT READING      1
RAW STRAIN DATA
      -.44          -.52          +4.51           -.39          +8.11
      -.44          +.34          +3.23           -.39           -.90
      -.18          +.72          +1.95           -.59          -1.92
     +8.81         +1.38          -2.54           +.05          -1.92
    +12.23         +1.15          -2.10           +.68          -1.66
    -12.45          +.04          -1.71           +.44          -1.28
     -9.42         -1.07          -2.12           +.19          -1.51
SHEAR FORCES
    -78.24        -92.11        +803.69         -69.35       +1445.73
    -78.24        +59.97        +575.36         -69.35        -161.28
    -32.04       +128.72        +347.03        -105.70        -341.43
  +1569.85       +245.41        -452.61          +8.11        -342.23
  +2179.76       +204.69        -373.66        +121.93        -294.20
  -2219.13         +7.17        -304.54         +77.86        -258.43
  -1678.68       -190.34        -377.67         +33.80        -268.67
SHEAR DIFFERENCES
     +0.00       +152.08        -228.33          +0.00       -1607.00
    +46.20        +68.75        -228.33         -36.35        -180.15
  +1601.89       +116.70        -799.64        +113.81           -.80
   +609.91        -40.73         +78.95        +113.81         +46.03
  -4398.89       -197.51         +69.12         -44.06         +67.76
   +540.46       -197.51         -73.13         -44.06         -40.24
REACTION LOADS (ACTUAL)
     +0.00         +0.00          +0.00          +0.00          +0.00
     +0.00         +0.00          +0.00          +0.00          +0.00
  +8747.31      -9088.86      +26498.02      -12192.12      +22747.34
     +0.00         +0.00          +0.00          +0.00          +0.00
     +0.00         +0.00          +0.00          +0.00          +0.00
     +0.00         +0.00          +0.00          +0.00          +0.00
REACTION LOADS (APPROX)
     +0.00         +0.00          +0.00          +0.00          +0.00
     +0.00         +0.00          +0.00          +0.00          +0.00
  +8747.31      -9088.86      +26498.02      -12192.12      +22747.34
     +0.00         +0.00          +0.00          +0.00          +0.00
     +0.00         +0.00          +0.00          +0.00          +0.00
     +0.00         +0.00          +0.00          +0.00          +0.00
APPROXIMATE LOADS
     +0.00       +201.52        -302.67          +0.00       -2090.40
    +69.01       +104.21        -346.17         -55.11        -269.09
 -11425.98     +14796.14      -43876.75      +19779.33      -36375.69
   +832.09        -56.83        +110.23        +158.82         +62.80
  -5846.44       -269.56         +94.40         -60.14         +90.06
   +714.35       -266.79         -98.83         -59.52         -53.18
ACTUAL LOADS
    +19.55       +188.93        -307.55        +265.72       -2056.87
    +25.44        +52.82        -247.55          -6.95        -271.58
 -12723.97     +18908.32      -46632.31      +25658.25      -38055.85
   +499.07       +442.70        -432.22       +1016.97        -233.22
  -5837.88       +733.58        -182.24         +29.64         -33.49
   +709.17       -233.89        -123.61         +49.38         -89.30
```

```
CURRENT READING       2
RAW STRAIN DATA                                                  +.98          +10.73
      -3.06          -.43            +6.44                       +.98            -.50
      -3.06         +1.14            +5.17                      -1.68           -2.05
      -2.30         +1.32            +3.91                       -.79           -2.76
     +32.44         +2.65            -4.49                       +.10           -2.66
     +45.73         +2.85            -3.99                       -.07           -2.10
     -42.85          -.92            -2.68                       -.24           -2.02
     -31.04         -4.70            -2.58
SHEAR FORCES
    -544.63        -76.79         +1147.69                    +175.43        +1912.46
    -544.63       +202.55          +922.15                    +175.43          -88.51
    -409.99       +324.39          +696.60                    -298.94         -365.78
   +5783.54       +472.95          -799.92                    -140.47         -528.73
   +8151.76       +508.30          -711.39                     +17.99         -474.12
   -7638.05       -164.65          -478.28                     -12.40         -373.97
   -5533.04       -837.61          -459.15                     -42.80         -359.72
SHEAR DIFFERENCES
      +0.00       +279.34          -225.54                      +0.00        -2000.97
    +134.64       +121.85          -225.54                    -474.37         -277.27
   +6193.52       +148.56         -1496.52                    +158.47         -162.55
   +2368.22        +35.35           +88.53                    +158.47          +54.21
  -15789.81       -672.95          +233.11                     -30.40         +100.14
   +2105.01       -672.95           +19.13                     -30.40          +14.25
REACTION LOADS (ACTUAL)
      +0.00         +0.00            +0.00                      +0.00           +0.00
      +0.00         +0.00            +0.00                      +0.00           +0.00
  +12759.76      -8930.12        +38281.19                  -10783.41       +31357.46
      +0.00         +0.00            +0.00                      +0.00           +0.00
      +0.00         +0.00            +0.00                      +0.00           +0.00
      +0.00         +0.00            +0.00                      +0.00           +0.00
REACTION LOADS (APPROX)
      +0.00         +0.00            +0.00                      +0.00           +0.00
      +0.00         +0.00            +0.00                      +0.00           +0.00
  +12759.76      -8930.12        +38281.19                  -10783.41       +31357.46
      +0.00         +0.00            +0.00                      +0.00           +0.00
      +0.00         +0.00            +0.00                      +0.00           +0.00
      +0.00         +0.00            +0.00                      +0.00           +0.00
APPROXIMATE LOADS
      +0.00       +370.16          -298.98                      +0.00        -2607.38
    +201.11       +184.70          -341.95                    -719.05         -414.16
  -10499.82     +14592.20        -63936.50                  +17586.92       -50402.45
   +3230.93        +49.33          +123.60                    +221.13          +73.96
  -20985.80       -918.43          +318.36                     -41.49         +133.10
   +2782.28       -908.98           +25.86                     -41.06          +18.84
ACTUAL LOADS
     +75.18       +318.65          -320.62                    +318.85        -2565.98
      -5.05        +50.07          -116.89                    -658.31         -329.32
  -11889.92     +20084.08        -66576.21                  +25903.74       -52022.13
   +2606.58       +345.90          -420.22                   +1410.51         -243.72
  -20822.72      +2490.30          -323.27                     +58.93          -44.56
   +2835.97      -1030.21           +85.31                     +54.79          -24.03
```

```
CURRENT READING       3
RAW STRAIN DATA
        -4.26           -.32           +9.25           +1.80          +15.07
        -4.26          +1.74           +7.58           +1.80            -.37
        -3.80          +2.73           +5.91           -2.58           -2.56
       +50.84          +3.71           -6.49           -1.20           -4.49
       +71.11          +4.24           -6.09            +.18           -3.76
       -66.03          +6.40           -4.21            -.14           -3.15
       -47.62          +8.55           -3.46            -.46           -2.90
SHEAR FORCES
      -759.98         -57.47        +1649.42         +320.44        +2636.17
      -759.98        +310.66        +1351.11         +320.44          -65.70
      -677.04        +486.30        +1052.79         -459.80         -455.90
     +9062.36        +661.14        -1156.46         -213.85         -799.56
    +12676.54        +756.03        -1085.51          +32.10         -669.62
    -11771.83       +1140.38         -750.38          -24.74         -560.95
     -8489.97       +1524.73         -616.00          -81.77         -516.57
SHEAR DIFFERENCES
        +0.00        +368.12         -298.31           +0.00        -2751.82
       +82.94        +175.64         -298.31         -780.24         -390.29
     +9739.40        +174.84        -2209.25         +245.95         -343.53
     +3614.19         +94.89          +70.94         +245.95         +129.74
    -24448.37        +384.35         +335.13          -57.03         +108.67
     +3281.86        +384.35         +134.38          -57.03          +44.37
REACTION LOADS (ACTUAL)
        +0.00          +0.00           +0.00           +0.00           +0.00
        +0.00          +0.00           +0.00           +0.00           +0.00
    +25900.32      -41411.40       +63000.15       -16992.46       +45760.01
        +0.00          +0.00           +0.00           +0.00           +0.00
        +0.00          +0.00           +0.00           +0.00           +0.00
        +0.00          +0.00           +0.00           +0.00           +0.00
REACTION LOADS (APPROX)
        +0.00          +0.00           +0.00           +0.00           +0.00
        +0.00          +0.00           +0.00           +0.00           +0.00
    +25900.32      -41411.40       +63000.15       -16992.46       +45760.01
        +0.00          +0.00           +0.00           +0.00           +0.00
        +0.00          +0.00           +0.00           +0.00           +0.00
        +0.00          +0.00           +0.00           +0.00           +0.00
APPROXIMATE LOADS
        +0.00        +487.82         -395.44           +0.00        -3579.57
      +123.88        +266.24         -452.28        -1182.71         -532.96
    -25842.31      +66841.75      -104813.98       +27707.36       -73722.51
     +4930.78        +132.41          +99.05         +343.21         +177.28
    -32493.66        +524.55         +457.69          -77.84         +144.44
     +4337.78        +519.15         +181.60          -77.04          +58.65
ACTUAL LOADS
      +164.68        +332.87         -373.71         +414.18        -3522.67
      -129.83          -6.03          -30.95        -1137.56         -422.63
    -31186.67      +76452.55      -112133.14       +40915.05       -76301.15
     +3501.50        +924.86        -1239.37        +2311.98         -356.82
    -32608.93       +5995.94         -902.79         +161.45         -129.47
     +4078.87        +365.76          -76.51         +105.05          -10.87
```

```
CURRENT READING      4
RAW STRAIN DATA
          +7.56            -.41          +10.64           -1.77          +18.27
          +7.56            +.39           +7.28           -1.77           -1.48
         -13.70            +.74           +3.91            -.66           -4.43
          -2.06           +1.39           -5.01            +.35           -4.91
          -1.34            +.69           -4.41           +1.36           -4.14
           -.73            +.49           -3.73            +.91           -2.86
          -2.09            +.29           -5.48            +.45           -3.06
SHEAR FORCES
       +1347.04          -72.79        +1897.50         -315.51        +3256.44
       +1347.04          +69.19        +1297.49         -315.51         -264.69
       -2442.84         +131.85         +697.48         -117.36         -790.06
        -367.61         +248.37         -893.23          +62.17         -875.12
        -238.19         +122.34         -785.55         +241.70         -738.39
        -129.35          +86.65         -664.90         +161.34         -510.29
        -372.13          +50.95         -977.76          +80.98         -545.30
SHEAR DIFFERENCES
          +0.00         +141.98         -600.01           +0.00        -3521.13
       -3789.88          +62.66         -600.01         +198.15         -525.37
       +2075.24         +116.52        -1590.71         +179.53          -85.06
        +129.42         -126.03         +107.68         +179.53         +136.73
        +108.84          -35.70         +120.65          -80.36         +228.10
        -242.78          -35.70         -312.86          -80.36          -35.01
REACTION LOADS (ACTUAL)
          +0.00           +0.00           +0.00           +0.00           +0.00
          +0.00           +0.00           +0.00           +0.00           +0.00
      +25197.72       -19310.42       +60580.51       -30042.71       +52466.81
          +0.00           +0.00           +0.00           +0.00           +0.00
          +0.00           +0.00           +0.00           +0.00           +0.00
          +0.00           +0.00           +0.00           +0.00           +0.00
REACTION LOADS (APPROX)
          +0.00           +0.00           +0.00           +0.00           +0.00
          +0.00           +0.00           +0.00           +0.00           +0.00
      +25197.72       -19310.42       +60580.51       -30042.71       +52466.81
          +0.00           +0.00           +0.00           +0.00           +0.00
          +0.00           +0.00           +0.00           +0.00           +0.00
          +0.00           +0.00           +0.00           +0.00           +0.00
APPROXIMATE LOADS
          +0.00         +188.14         -795.37           +0.00        -4580.31
       -5660.96          +94.98         -909.69         +300.35         -784.75
      -36974.29       +31225.00       -99930.57       +48576.33       -84033.70
        +176.56         -175.87         +150.33         +250.53         +186.54
        +144.65          -48.72         +164.77         -109.68         +303.16
        -320.89          -48.22         -422.78         -108.55          -46.28
ACTUAL LOADS
          -2.04         +141.78         -751.73         +583.14        -4499.88
       -5568.49         +743.81         -818.71         +439.94         -826.67
      -39897.88       +41531.74      -106381.35       +62064.53       -88125.86
        -309.06        +1382.39        -1152.73        +2238.34         -507.13
         +20.24          +63.75         -209.15          +55.99          +20.12
        -384.49         +219.26         -574.81         +170.98         -142.05
```

```
CURRENT READING       5
RAW STRAIN DATA
      +19.50          +1.01           +11.95            -.24          +19.58
      +19.50           +.61            +8.84            -.24           -1.08
      -51.03           +.59            +5.73           -1.77           -4.04
       -1.66           +.18            -6.13            -.37           -5.39
        -.90           -.32            -5.92           +1.04           -4.92
        -.59           -.44            -4.89            +.44           -3.37
       -1.83           -.57            -6.55            -.15           -3.62
SHEAR FORCES
    +3475.64        +180.52         +2130.09          -43.41        +3490.25
    +3475.64        +108.89         +1575.69          -43.41         -192.44
    -9097.28        +105.91         +1021.28         -314.96         -719.55
     -295.71         +32.33         -1092.39          -65.18         -960.59
     -161.07         -56.80         -1055.05         +184.60         -876.27
     -105.50         -79.26          -872.59          +78.73         -600.81
     -326.86        -101.73         -1167.87          -27.13         -645.23
SHEAR DIFFERENCES
      +0.00          -71.63          -554.40           +0.00        -3682.68
   -12572.92          -2.98          -554.40         -271.55         -527.11
    +8801.57         -73.58         -2113.68         +249.78         -241.04
     +134.64         -89.12           +37.35         +249.78          +84.33
      +55.57         -22.47          +182.45         -105.87         +275.45
     -221.36         -22.47          -295.27         -105.87          -44.41
REACTION LOADS (ACTUAL)
      +0.00           +0.00            +0.00           +0.00           +0.00
      +0.00           +0.00            +0.00           +0.00           +0.00
   +36822.16      -12823.11        +68908.44       -27045.54       +57629.28
      +0.00           +0.00            +0.00           +0.00           +0.00
      +0.00           +0.00            +0.00           +0.00           +0.00
      +0.00           +0.00            +0.00           +0.00           +0.00
REACTION LOADS (APPROX)
      +0.00           +0.00            +0.00           +0.00           +0.00
      +0.00           +0.00            +0.00           +0.00           +0.00
   +36822.16      -12823.11        +68908.44       -27045.54       +57629.28
      +0.00           +0.00            +0.00           +0.00           +0.00
      +0.00           +0.00            +0.00           +0.00           +0.00
      +0.00           +0.00            +0.00           +0.00           +0.00
APPROXIMATE LOADS
      +0.00          -94.92          -734.91           +0.00        -4790.46
   -18780.23          -4.51          -840.54         -411.62         -787.35
   -44806.66      +20492.37       -114157.01       +43871.88       -92538.24
     +183.69        -124.37           +52.14         +348.55         +115.05
      +73.85         -30.66          +249.18         -144.48         +366.10
     -292.59         -30.34          -399.02         -143.00          -58.70
ACTUAL LOADS
       -.81         -273.89          -626.48         +584.52        -4709.14
   -18654.20       +2227.28          -812.67         -260.13         -740.04
   -47371.88      +32686.27       -119618.57       +58928.55       -96348.61
     -148.66       +1652.09         -1188.69        +2567.07         -573.37
      -25.75         +33.53          -173.19           -4.71          +57.69
     -342.21        +245.81          -548.44         +150.02         -150.75
```

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CURRENT READING      6
RAW STRAIN DATA
    +26.42         +2.02          +13.05          +.87          +20.68
    +26.42          +.96           +9.98          +.87            -.42
    -77.61          +.55           +6.91         -2.58           -3.85
     -1.31          -.47           -6.97          -.97           -6.31
      -.77          -.74           -6.83          +.65           -5.49
      -.61          -.96           -5.72          +.11           -3.94
     -1.79         -1.18           -7.37          -.43           -4.05
SHEAR FORCES
  +4710.12       +359.31        +2325.76       +154.36        +3686.97
  +4710.12       +171.38        +1778.59       +154.36          -75.45
 -13836.02        +97.73        +1231.41       -460.15         -685.95
   -234.25        -83.27        -1241.76       -172.07        -1124.07
   -136.69       -131.83        -1218.17       +116.01         -978.81
   -108.28       -171.27        -1020.57        +19.46         -703.00
   -319.20       -210.71        -1313.06        -77.10         -721.65
SHEAR DIFFERENCES
     +0.00       -187.92         -547.18         +0.00        -3762.42
 -18546.14        -73.66         -547.18       -614.51         -610.50
 +13601.77       -181.00        -2473.17       +288.08         -438.11
    +97.56        -48.56          +23.59       +288.08         +145.26
    +28.41        -39.44         +197.60        -96.55         +275.80
   -210.92        -39.44         -292.49        -96.55          -18.65
REACTION LOADS (ACTUAL)
     +0.00         +0.00           +0.00         +0.00           +0.00
     +0.00         +0.00           +0.00         +0.00           +0.00
 +40546.53      -7623.99       +74878.99     -25041.03       +62571.47
     +0.00         +0.00           +0.00         +0.00           +0.00
     +0.00         +0.00           +0.00         +0.00           +0.00
     +0.00         +0.00           +0.00         +0.00           +0.00
REACTION LOADS (APPROX)
     +0.00         +0.00           +0.00         +0.00           +0.00
     +0.00         +0.00           +0.00         +0.00           +0.00
 +40546.53      -7623.99       +74878.99     -25041.03       +62571.47
     +0.00         +0.00           +0.00         +0.00           +0.00
     +0.00         +0.00           +0.00         +0.00           +0.00
     +0.00         +0.00           +0.00         +0.00           +0.00
APPROXIMATE LOADS
     +0.00       -249.03         -725.33         +0.00        -4894.18
 -27702.46       -111.65         -829.58       -931.48         -911.91
 -43086.35     +11963.16      -124331.57     +40711.58      -100756.24
   +133.10        -67.76          +32.94       +402.00         +178.18
    +37.76        -53.83         +269.86       -131.77         +366.56
   -278.78        -53.27         -395.25       -130.42          -24.65
ACTUAL LOADS
    -11.19       -509.63         -578.61       +582.23        -4812.41
 -27568.80      +3212.51         -839.84       -755.40         -788.57
 -45321.97     +24970.77      -129011.18     +57039.85      -104381.50
    -86.48      +1790.02        -1144.02      +2776.10         -483.83
    -16.42        -24.19         -185.51          -.09          +28.53
   -308.89       +225.58         -540.86       +170.07         -121.20
```

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CURRENT READING      7
RAW STRAIN DATA
        -.21             -.44           +17.91            -1.49           +22.38
        -.21             +.82            +3.77            -1.49            -1.25
       +2.20            +1.49           -10.37             -.49            -4.76
       -2.51            +1.40            -5.79             +.79            -6.64
       -1.82             +.81            -5.05            +2.06            -5.40
       -1.28             +.53            -3.81            +1.18            -3.51
       -3.44             +.25            -6.16             +.30            -3.83
SHEAR FORCES
      -37.68           -77.83         +3193.08          -265.89         +3989.54
      -37.68          +145.97          +672.16          -265.89          -227.08
     +391.52          +265.03         -1848.77           -86.72          -847.86
     -446.64          +250.46         -1032.16          +140.60         -1184.30
     -324.01          +144.10          -900.11          +367.92          -563.49
     -227.71           +94.57          -678.48          +210.43          -625.36
     -612.72           +45.03         -1097.54           +52.95          -683.18
SHEAR DIFFERENCES
       +0.00          +223.80         -2520.93            +0.00         -4212.62
     +429.20          +119.06         -2520.93          +179.17          -624.78
     -838.17           -14.57          +816.62          +227.32          -336.44
     +122.63          -106.36          +132.05          +227.32          +220.82
      +96.30           -49.54          +221.62          -157.48          +338.17
     -385.01           -49.54          -419.05          -157.48           -57.82
REACTION LOADS (ACTUAL)
       +0.00            +0.00            +0.00            +0.00            +0.00
       +0.00            +0.00            +0.00            +0.00            +0.00
   +12656.19        -15335.00        +62947.50        -29288.44        +63841.89
       +0.00            +0.00            +0.00            +0.00            +0.00
       +0.00            +0.00            +0.00            +0.00            +0.00
       +0.00            +0.00            +0.00            +0.00            +0.00
REACTION LOADS (APPROX)
       +0.00            +0.00            +0.00            +0.00            +0.00
       +0.00            +0.00            +0.00            +0.00            +0.00
   +12656.19        -15335.00        +62947.50        -29288.44        +63841.89
       +0.00            +0.00            +0.00            +0.00            +0.00
       +0.00            +0.00            +0.00            +0.00            +0.00
       +0.00            +0.00            +0.00            +0.00            +0.00
APPROXIMATE LOADS
       +0.00          +296.57         -3341.70            +0.00         -5479.80
     +641.10          +180.48         -3822.02          +271.59          -933.24
   -21578.32        +24624.59        -99865.74        +47440.80       -102625.15
     +167.30          -148.42          +184.36          +317.21          +301.25
     +127.99           -67.61          +302.67          -214.93          +449.39
     -508.88           -66.91          -566.29          -212.72           -76.42
ACTUAL LOADS
      -50.75          +647.98         -3350.64         +1026.73         -5430.31
     +614.86          +542.79         -3813.05          +892.12         -1036.06
   -23884.14        +33749.71       -105874.33        +62311.38       -106664.00
     -305.43         +1242.04         -1017.44         +2441.43          -376.28
      +41.41            -7.96           -20.61          -109.06          +131.20
     -563.99          +226.45          -689.75          +106.30          -167.04
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CURRENT READING        8
RAW STRAIN DATA
          +.65           +.85         +27.67          +2.18          +27.17
          +.65          +1.57          -7.33          +2.18            -.03
         +3.32          +1.62         -42.33          -1.51           -3.07
         -3.37           -.24          -6.09           -.25           -7.44
         -2.37           -.24          -5.39          +1.01           -6.64
         -2.14           -.50          -3.88           +.15           -4.44
         -4.26           -.75          -6.10           -.71           -4.91
SHEAR FORCES
       +116.04        +151.62       +4932.60        +387.99        +4130.72
       +116.04        +279.32       -1307.08        +387.99           -5.64
       +591.55        +289.23       -7546.76        -269.17         -547.73
       -600.89         -42.53       -1084.91         -44.93        -1326.01
       -422.72         -43.39        -961.56        +179.20        -1183.54
       -380.74         -88.75        -692.41         +26.33         -791.27
       -759.30        -134.11       -1088.13        -126.54         -858.31
SHEAR DIFFERENCES
         +0.00        +127.70       -6239.68          +0.00        -4136.36
       +475.51          +9.91       -6239.68        -657.16         -542.09
      -1192.44        -331.76       +6461.85        +224.19         -778.28
       +178.16           -.86        +123.35        +224.19         +142.47
        +41.99         -45.36        +269.15        -152.87         +392.27
       -378.57         -45.36        -395.72        -152.87          -67.05
REACTION LOADS (ACTUAL)
         +0.00          +0.00          +0.00          +0.00           +0.00
         +0.00          +0.00          +0.00          +0.00           +0.00
     +13718.08       +3302.46      +41264.09       -3956.19       +65149.12
         +0.00          +0.00          +0.00          +0.00           +0.00
         +0.00          +0.00          +0.00          +0.00           +0.00
         +0.00          +0.00          +0.00          +0.00           +0.00
REACTION LOADS (APPROX)
         +0.00          +0.00          +0.00          +0.00           +0.00
         +0.00          +0.00          +0.00          +0.00           +0.00
     +13718.08       +3302.46      +41264.09       -3956.19       +65149.12
         +0.00          +0.00          +0.00          +0.00           +0.00
         +0.00          +0.00          +0.00          +0.00           +0.00
         +0.00          +0.00          +0.00          +0.00           +0.00
APPROXIMATE LOADS
         +0.00        +169.23       -8271.20          +0.00        -5330.61
       +710.27         +15.02       -9460.06        -996.14         -609.72
     -23842.85       -5841.30      -55939.20       +6719.13      -105422.02
       +243.07          -1.20        +172.21        +312.84         +194.36
        +55.80         -61.90        +367.58        -208.63         +521.35
       -500.37         -61.27        -534.76        -206.49          -88.62
ACTUAL LOADS
       -132.33       +1199.38       -8351.03       +1694.35        -5444.31
       +558.20       +1334.95       -9720.40        +611.28         -917.48
     -23753.93        +231.26      -57053.07      +18599.50      -106306.78
       +156.73        +799.60        -161.81       +1890.82          +24.03
        -13.14        -154.83        +280.05        -308.20         +219.87
       -521.87        +162.42        -550.36         +39.17         -137.13
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CURRENT READING        9
RAW STRAIN DATA
      +1.24           +1.88           +36.03          +4.86          +23.92
      +1.24           +2.26           -16.50          +4.86            +.78
      +4.21           +1.37           -69.03          -2.10           -1.91
      -4.08           -1.77            -6.41          -1.00           -8.33
      -2.91            -.66            -5.61           +.11           -7.39
      -2.89           -1.03            -4.00           -.66           -5.17
      -5.01           -1.39            -5.98          -1.42           -5.47
SHEAR FORCES
    +220.50         +335.46         +6422.29        +867.26        +4263.38
    +220.50         +402.92         -2941.79        +867.26         +139.72
    +750.85         +244.83        -12305.87        -374.67         -340.56
    -728.15         -315.68         -1143.40        -177.64        -1484.61
    -517.95         -118.25         -1000.90         +19.39        -1316.89
    -516.00         -183.11          -712.61        -116.94         -921.31
    -893.18         -247.96         -1066.37        -253.28         -975.65
SHEAR DIFFERENCES
      +0.00          +67.47         -9364.08          +0.00        -4123.66
    +530.35         -158.09         -9364.08       -1241.93         -480.28
   -1478.99         -560.51        +11162.47        +197.03        -1144.05
    +210.20         +197.43          +142.50        +197.03         +167.72
      +1.95          -64.86          +288.30        -136.33         +395.58
    -377.18          -64.86          -353.77        -136.33          -54.34
REACTION LOADS (ACTUAL)
      +0.00           +0.00            +0.00          +0.00           +0.00
      +0.00           +0.00            +0.00          +0.00           +0.00
  +14730.45       +17377.69        +24231.55      +15835.95       +65906.46
      +0.00           +0.00            +0.00          +0.00           +0.00
      +0.00           +0.00            +0.00          +0.00           +0.00
      +0.00           +0.00            +0.00          +0.00           +0.00
REACTION LOADS (APPROX)
      +0.00           +0.00            +0.00          +0.00           +0.00
      +0.00           +0.00            +0.00          +0.00           +0.00
  +14730.45       +17377.69        +24231.55      +15835.95       +65906.46
      +0.00           +0.00            +0.00          +0.00           +0.00
      +0.00           +0.00            +0.00          +0.00           +0.00
      +0.00           +0.00            +0.00          +0.00           +0.00
APPROXIMATE LOADS
      +0.00          +89.41        -12412.85          +0.00        -5364.08
    +792.18         -239.64        -14197.01       -1882.54         -717.40
  -25919.91       -28832.15        -21006.52      -25136.51      -107217.93
    +286.77         +275.50          +198.94        +274.94         +228.81
      +2.59          -88.51          +393.73        -186.06         +525.75
    -498.53          -87.60          -478.07        -184.15          -71.82
ACTUAL LOADS
    -203.34        +1695.58        -12552.24       +2262.36        -5520.66
    +549.11        +1882.63        -14682.95        +547.58         -848.92
  -24013.46       -25160.44        -18365.06      -15647.25      -105637.91
    +472.55         +609.24          +524.08       +1398.01         +461.23
     -52.24         -292.63          +495.45        -438.85         +238.36
    -489.16          +79.15          -406.54          -4.85          -88.98
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CURRENT READING        10
RAW STRAIN DATA
        +.54            -.81           +13.80          -2.18       [illegible]
        +.54           +1.44            +8.78          -2.18           -1.06
       +2.46           +2.37            +3.76           -.79            5.27
       -2.79           +2.91            +3.54          +1.13           -7.66
       -1.59           +2.08            +7.63          +3.16       [illegible]
        -.85            +.92           -18.18          +1.29           -5.64
       -3.63            -.24           -16.85           -.58       [illegible]
SHEAR FORCES
      +96.72         -144.51         +2460.34         -387.76         +478.73
      +96.72         +256.69         +1565.59         -387.76         -189.17
     +437.83         +422.41          +670.84         -141.39      [illegible]
     -498.17         +518.56          +631.10         +210.67        -1764.83
     -283.28         +370.42         +1364.64         +562.72        -1109.37
     -152.16         +163.68         -3240.92         +229.84         -648.73
     -647.89          -43.06         -3003.43         -103.04      [illegible]
SHEAR DIFFERENCES
       +0.00         +401.20          -894.75           +0.00      [illegible]
     +341.11         +165.72          -894.75         +246.37         -749.78
     -936.01          +96.16           -39.73         +352.06      [illegible]
     +214.90         -148.14          +733.53         +352.06         +778.47
     +131.12         -206.74         -4605.56         -332.88         +477.41
     -495.73         -206.74          +237.44         -332.88          +10.21
REACTION LOADS (ACTUAL)
       +0.00           +0.00            +0.00           +0.00           +0.00
       +0.00           +0.00            +0.00           +0.00           +0.00
   +17757.66       -26144.67        +85517.06       -42093.83       +74219.04
       +0.00           +0.00            +0.00           +0.00           +0.00
       +0.00           +0.00            +0.00           +0.00           +0.00
       +0.00           +0.00            +0.00           +0.00           +0.00
REACTION LOADS (APPROX)
       +0.00           +0.00            +0.00           +0.00           +0.00
       +0.00           +0.00            +0.00           +0.00           +0.00
   +17757.66       -26144.67        +85517.06       -42093.37       +71717.84
       +0.00           +0.00            +0.00           +0.00           +0.00
       +0.00           +0.00            +0.00           +0.00           +0.00
       +0.00           +0.00            +0.00           +0.00           +0.00
APPROXIMATE LOADS
       +0.00         +531.65         -1186.06           +0.00        -6071.99
     +509.52         +251.20         -1356.54         +373.45        -1119.94
   -29892.34       +42176.99       -137519.25       +68323.45      -119741.74
     +293.18         -206.72         +1024.11         +491.27         +323.11
     +174.27         -282.15         -6289.83         -454.71         +637.51
     -655.23         -279.25          +320.87         -449.63          -21.43
ACTUAL LOADS
      -26.37         +553.49         -1144.24         +773.74        -5559.81
     +570.94         +154.21         -1199.27         +547.50        -1141.16
   -33647.93       +54662.22       -146321.30       +87043.17      -125089.30
     -411.55        +1585.03          -848.83        +3106.86         -638.84
      -88.49         +918.32         -6692.19         +787.54         +111.56
     -704.64          +26.05          +154.98         -138.49         -109.77
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CURRENT READING      9
RAW STRAIN DATA
       +1.24           +1.88           +36.03            +4.06          [illegible]
       +1.24           +2.26           -16.50            +4.06            +.78
       +4.21           +1.37           -69.03            -2.10            -1.01
       -4.08           -1.77            -6.41            -1.00            -8.53
       -2.91            -.66            -5.61             +.11          [illegible]
       -2.89           -1.03            -4.00             -.66            -5.17
       -5.01           -1.39            -5.98            -1.42            -5.47
SHEAR FORCES
     +220.50         +335.46         +6422.29          +867.26        [illegible]
     +220.50         +402.92         -2941.79          +867.26         +179.73
     +750.85         +244.83        -12305.87          -374.67         [illegible]
     -728.15         -315.68         -1143.40          -177.64        -1184.81
     -517.95         -118.25         -1000.90           +19.39         [illegible]
     -516.00         -183.11          -712.61          -116.94         [illegible]
     -893.18         -247.96         -1066.37          -253.28         [illegible]
SHEAR DIFFERENCES
       +0.00          +67.47         -9364.08            +0.00         +123.66
     +530.35         -158.09         -9364.08         -1241.93         -434.28
    -1478.99         -560.51        +11162.47          +197.03        -1111.05
     +210.20         +197.43          +142.50          +197.03         +167.72
       +1.95          -64.86          +288.30          -136.33         +395.50
    -377.18           -64.86          -353.77          -136.33          -54.34
REACTION LOADS (ACTUAL)
       +0.00           +0.00            +0.00            +0.00           +0.00
       +0.00           +0.00            +0.00            +0.00           +0.00
   +14730.45       +17377.69        +24231.55        +15835.95       +65996.46
       +0.00           +0.00            +0.00            +0.00           +0.00
       +0.00           +0.00            +0.00            +0.00           +0.00
       +0.00           +0.00            +0.00            +0.00           +0.00
REACTION LOADS (APPROX)
       +0.00           +0.00            +0.00            +0.00           +0.00
       +0.00           +0.00            +0.00            +0.00           +0.00
   +14730.45       +17377.69        +24231.55        +15835.95       +65996.46
       +0.00           +0.00            +0.00            +0.00           +0.00
       +0.00           +0.00            +0.00            +0.00           +0.00
       +0.00           +0.00            +0.00            +0.00           +0.00
APPROXIMATE LOADS
       +0.00          +89.41        -12412.85            +0.00        -5364.08
     +792.18         -239.64        -14197.01         -1882.54         -717.40
   -25919.91       -28832.15        -21006.52        -25136.51      -107217.93
     +286.77         +275.50          +198.94          +274.94         +228.91
       +2.59          -88.51          +393.73          -186.06         +525.75
     -498.53          -87.60          -478.07          -184.15          -71.82
ACTUAL LOADS
     -203.34        +1685.58        -12552.24         +2262.36        -5520.66
     +549.11        +1882.63        -14682.95          +547.58         -848.92
   -24013.46       -25160.44        -18365.06        -15647.25      -105637.91
     +472.55         +609.24          +524.08         +1398.01         +461.23
      -52.24         -292.63          +495.45          -438.85         +278.36
     -489.16          +79.15          -406.54            -4.85          -88.93
```

```
CURRENT READING       10
RAW STRAIN DATA
     +.54            -.21           +13.90          -2.18        [illegible]
     +.54           +1.44            +8.78          -2.10        [illegible]
    +2.46           +2.37            +2.76           -.75        [illegible]
    -2.79           +2.91            +3.54          +1.13        [illegible]
    -1.59           +2.08            +7.65          +7.16        [illegible]
     -.85            +.92           -18.18          +1.20        [illegible]
    -3.63           -7.24           -16.35           -.52        [illegible]
SHEAR FORCES
   +96.72         -144.51         +2460.34        -387.76        [illegible]
   +96.72         +256.67         +1565.59        -387.76        [illegible]
  +437.83         +422.41          +670.94        -141.30        [illegible]
  -498.17         +518.56          +631.10        +210.67        [illegible]
  -283.28         +370.42         +1364.64        +562.72        [illegible]
  -152.16         +163.68         -3240.92        +229.24        [illegible]
  -647.87          -43.06         -3003.42        -103.04        [illegible]
SHEAR DIFFERENCES
    +0.00         +401.20          -894.75          +0.00        [illegible]
  +341.11         +165.72          -894.75        +246.77           749.72
  -936.01          +96.16           -39.73        +357.36        [illegible]
  +214.90         -148.14          +733.53        +352.46        [illegible]
  +131.12         -206.74         -4605.56        -330.80        [illegible]
  -495.73         -206.74          +237.44        -330.80            16.71
REACTION LOADS (ACTUAL)
    +0.00           +0.00            +0.00          +0.00            +0.00
    +0.00           +0.00            +0.00          +0.00            +0.00
+17757.66       -26144.67        +85517.06      -42093.87        +74219.04
    +0.00           +0.00            +0.00          +0.00            +0.00
    +0.00           +0.00            +0.00          +0.00            +0.00
    +0.00           +0.00            +0.00          +0.00            +0.00
REACTION LOADS (APPROX)
    +0.00           +0.00            +0.00          +0.00            +0.00
    +0.00           +0.00            +0.00          +0.00            +0.00
+17757.66       -26144.67        +85517.06      -42093.87        +74219.04
    +0.00           +0.00            +0.00          +0.00            +0.00
    +0.00           +0.00            +0.00          +0.00            +0.00
    +0.00           +0.00            +0.00          +0.00            +0.00
APPROXIMATE LOADS
    +0.00         +531.65         -1186.06          +0.00         -2071.90
  +509.52         +251.20         -1356.54        +373.45         -1119.74
-29892.34       +42176.99       -137519.25      +68323.45       -119761.94
  +293.18         -206.72         +1024.11        +491.37          +725.11
  +174.27         -282.15         -6289.83        -454.71           637.31
  -655.23         -279.25          +320.87        -449.67           -71.45
ACTUAL LOADS
   -26.37         +553.49         -1144.24        +773.74         -5559.81
  +570.94         +154.21         -1199.27        +547.52         -1141.16
-33647.93       +54662.22       -146321.30      +87043.17       -125089.78
  -411.55        +1585.03          -848.83       +3106.86          -638.84
   -98.49         +918.32         -6692.19        +787.94           111.36
  -704.64          +26.05          +154.78        -130.49       [illegible]
```

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CURRENT READING       11
RAW STRAIN DATA
        +1.25             -.08            +10.10               +.29       [illegible]
        +1.25            +2.55             +6.44               +.29       [illegible]
        +3.44            +3.27             +2.79              -2.75       [illegible]
        -4.38            +3.64            +26.35               +.63            -9.14
        -2.28            +3.60            +37.43              +4.01       [illegible]
        -1.02             +.03            -50.56               -.01            -4.34
        -3.86            -3.54            -41.43              -4.02       [illegible]
SHEAR FORCES
      +222.59           -13.94          +1800.53             +51.65       [illegible]
      +222.59          +455.15          +1148.73             +51.65       [illegible]
      +613.49          +583.44           +496.92            -490.44       [illegible]
      -780.37          +649.48          +4697.34            +111.95       [illegible]
      -407.23          +641.48          +6671.79            +714.76       [illegible]
      -181.58            +5.43          -9013.42              -1.82       [illegible]
      -688.80          -630.61          -7384.81            -717.40       [illegible]
SHEAR DIFFERENCES
        +0.00          +469.09           -651.81              +0.00       [illegible]
      +390.90          +128.29           -651.81            -542.09       [illegible]
     -1393.86           +66.04          +4200.41            +602.40       [illegible]
      +373.14            -8.00          +1974.45            +602.40       [illegible]
      +225.65          -636.05         -15685.20            -715.58       [illegible]
      -507.22          -636.05          +1628.60            -715.88       [illegible]
REACTION LOADS (ACTUAL)
        +0.00            +0.00             +0.00              +0.00            +0.00
        +0.00            +0.00             +0.00              +0.00            +0.00
    +22556.02        -25011.02         +97348.28          -36430.85        +89626.73
        +0.00            +0.00             +0.00              +0.00            +0.00
        +0.00            +0.00             +0.00              +0.00            +0.00
        +0.00            +0.00             +0.00              +0.00            +0.00
REACTION LOADS (APPROX)
        +0.00            +0.00             +0.00              +0.00            +0.00
        +0.00            +0.00             +0.00              +0.00            +0.00
    +22556.02        -25011.02         +97348.28          -36430.85        +89626.73
        +0.00            +0.00             +0.00              +0.00            +0.00
        +0.00            +0.00             +0.00              +0.00            +0.00
        +0.00            +0.00             +0.00              +0.00            +0.00
APPROXIMATE LOADS
        +0.00          +621.62           -864.02              +0.00         -3896.27
      +583.89          +194.46           -988.21            -821.71         -1152.05
    -38297.36       +40306.46        -149720.72          +59523.70       [illegible]
      +509.08           -11.16          +2756.60            +840.61          +325.01
      +299.91          -868.06         -21421.38            -977.01          +821.15
      -670.42          -859.13          +2200.82            -966.96       [illegible]
ACTUAL LOADS
       -22.33          +561.83           -750.22            +667.14       [illegible]
      +700.88           -40.55           -794.00            -753.11          -956.45
    -41974.74       +54224.43        -157823.04          +77981.67       [illegible]
      -179.23         +1648.82           +623.06           +3789.67          -574.36
      -284.24         +2741.07         -21643.53           +2650.01           -44.17
      -638.18          -667.18          +2120.34            -797.19       [illegible]
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CURRENT READING      12
RAW STRAIN DATA
     +1.68          +.18            +7.70          +2.18          +26.42
     +1.68         +3.47            +5.00          +2.18           +1.17
     +4.25         +4.13            +2.11          -4.16           -3.67
     -5.52         +4.20           +42.28           +.23          -19.01
     -2.81         +4.77           +58.03          +4.63           -0.94
     -1.27          -.61           -72.96           -.87           -1.97
     -4.06         -6.00           -58.71          -3.37      [illegible]
SHEAR FORCES
   +300.23        +32.71         +1408.13        +707.38        +4715.77
   +300.23       +617.75          +892.21        +399.78         +897.72
   +758.33       +775.60          +376.22        -748.96         -511.72
   -984.93       +748.01         +7536.41         +41.89        -1919.72
   -501.76       +850.39        +10344.23        +804.73        -1457.67
   -227.01       -109.55        -13004.53        -155.85         -873.01
   -723.79      -1069.50        -10466.74       +1176.44     [illegible]
SHEAR DIFFERENCES
     +0.00       +585.04          -516.73          +0.00         +477.09
   +458.10       +117.84          -315.73       -1170.34         -719.63
  -1743.26        +12.42         +7160.13        +781.04        -1707.51
   +483.17       +102.36         +2807.82        +782.84         +778.03
   +274.75       -959.94        -23350.76        -980.50         -719.01
   -496.78       -959.94         +2539.79        -980.52         +822.77
REACTION LOADS (ACTUAL)
     +0.00         +0.00            +0.00          +0.00           +0.00
     +0.00         +0.00            +0.00          +0.00           +0.00
 +26083.46     -24588.36       +106650.52      -32268.87       +85554.79
     +0.00         +0.00            +0.00          +0.00           +0.00
     +0.00         +0.00            +0.00          +0.00           +0.00
     +0.00         +0.00            +0.00          +0.00           +0.00
REACTION LOADS (APPROX)
     +0.00         +0.00            +0.00          +0.00           +0.00
     +0.00         +0.00            +0.00          +0.00           +0.00
 +26083.46     -24588.36       +106650.52      -32268.87       +85554.79
     +0.00         +0.00            +0.00          +0.00           +0.00
     +0.00         +0.00            +0.00          +0.00           +0.00
     +0.00         +0.00            +0.00          +0.00           +0.00
APPROXIMATE LOADS
     +0.00       +775.27          -683.90          +0.00        -5503.85
   +684.27       +178.63          -782.21       -1713.30        +1074.76
 -44496.65     +39540.93       -159915.34      +53104.15      +138899.54
   +659.18       +142.86         +3920.10       +1092.41         -718.14
   +365.16      -1310.11        -31890.24       -1338.72         +709.81
   -656.61      -1296.62         +3432.15       -1324.50         +294.73
ACTUAL LOADS
    -31.53       +663.95          -533.99        +617.56        -5183.87
   +834.04       -148.99          -560.10       -1710.81         +763.76
 -48166.68     +54603.95       -167550.65      +74889.39      -117604.27
    -30.59      +1737.56         +1593.75       +3629.21         -542.70
   -437.56      +3971.93        -31990.15       +3940.00         -155.56
   -564.86      -1174.34         +3416.15       -1246.70         +374.58
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CURRENT READING       13
RAW STRAIN DATA
          +.57           -.84          +17.04          -2.68          +25.47
          +.57          +1.41          +17.10          -2.68           -2.86
         +2.59          +2.70          +17.16           -.42           -7.09
         -2.33          +2.25           -7.28          +1.61           +3.24
         -1.54          +1.78           -6.48          +3.65           +6.70
         -1.04          +1.06           -4.31          +1.48          -15.33
         -4.09           +.34           -7.01           -.68          -12.83
SHEAR FORCES
       +101.60        -149.04        +3037.97        -477.41        +4536.70
       +101.60        +251.47        +3048.54        -477.41         -509.58
       +462.38        +482.12        +3059.12         -75.23        -1264.08
       -415.31        +400.36        -1297.99        +287.88         -613.56
       -274.57        +316.45        -1155.85        +650.99        +1173.34
       -185.93        +188.14         -768.66        +264.66        -2733.47
       -728.32         +59.83        -1250.04        -121.66        -2234.90
SHEAR DIFFERENCES
         +0.00        +400.50          +10.57          +0.00        -5046.60
       +360.78        +230.65          +10.57        +402.18         -754.78
       -877.69         -81.76        -4357.11        +363.11        -1877.51
       +140.73         -83.90         +142.15        +363.11         +509.93
        +88.64        -128.31         +387.18        -386.33        -3856.74
       -542.39        -128.31         -481.38        -386.33         +446.52
REACTION LOADS (ACTUAL)
         +0.00          +0.00           +0.00          +0.00           +0.00
         +0.00          +0.00           +0.00          +0.00           +0.00
     +20227.88      -32688.29      +105856.58      -51181.74       +79451.56
         +0.00          +0.00           +0.00          +0.00           +0.00
         +0.00          +0.00           +0.00          +0.00           +0.00
         +0.00          +0.00           +0.00          +0.00           +0.00
REACTION LOADS (APPROX)
         +0.00          +0.00           +0.00          +0.00           +0.00
         +0.00          +0.00           +0.00          +0.00           +0.00
     +20227.88      -32688.29      +105856.58      -51181.74       +79451.56
         +0.00          +0.00           +0.00          +0.00           +0.00
         +0.00          +0.00           +0.00          +0.00           +0.00
         +0.00          +0.00           +0.00          +0.00           +0.00
APPROXIMATE LOADS
         +0.00        +530.73          +14.02          +0.00        -6564.77
       +538.90        +349.63          +16.03        +609.63        -1126.71
     -33749.11      +52408.60      -177151.38      +82848.26      -124045.53
       +192.00        -117.08         +198.46        +506.70         +695.76
       +117.81        -175.12         +528.78        -527.25        -5175.91
       -716.90        -173.32         -650.51        -521.82         +590.19
ACTUAL LOADS
         +3.84        +383.07          +61.12        +654.97        -6386.98
       +630.88          -1.43         +386.54        +515.61        -1226.42
     -38439.20      +68057.46      -187735.01     +104878.30      -131032.64
       -743.95       +2323.94        -1961.47       +3700.12         -613.87
        -22.44         +24.60         -227.95        +632.80        -5420.95
       -801.59        +261.85         -844.57        -116.54         +473.95
```

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CURRENT READING       14
RAW STRAIN DATA
          +.77             -.16            +17.83             +.15            +22.31
          +.77            +2.23            +12.06             +.15             -6.34
         +3.14            +3.14             +6.29            -1.70             -9.08
         -2.63            +1.80             -8.96            +1.28            +30.24
         -1.76            +1.47             -7.64            +4.27            +36.74
         -1.37             +.50             -4.61             +.20            -44.37
         -4.43             -.47             -7.25            -3.87            -34.27
SHEAR FORCES
       +137.11           -28.22          +3177.76           +27.27          +3976.83
       +137.11          +398.40          +2149.49           +27.27          -1130.79
       +560.39          +558.89          +1121.21          -303.47          -1618.90
       -469.45          +321.32          -1596.73          +228.77          +5390.05
       -314.09          +261.27          -1361.45          +761.01          +6549.22
       -244.95           +88.74           -821.76           +35.30          -7909.13
       -789.25           -83.80          -1292.52          -690.42          -6108.71
SHEAR DIFFERENCES
         +0.00          +426.62          -1028.28            +0.00          -5107.62
       +423.28          +160.50          -1028.28          -330.74           -488.12
      -1029.84          -237.58          -2717.94          +532.24          +7008.96
       +155.36           -60.05           +235.29          +532.24          +1159.16
        +69.15          -172.53           +539.69          -725.71         -14458.35
       -544.30          -172.53           -470.76          -725.71          +1800.42
REACTION LOADS (ACTUAL)
         +0.00            +0.00             +0.00            +0.00             +0.00
         +0.00            +0.00             +0.00            +0.00             +0.00
     +19657.66        -22939.01         +92051.67        -34042.51         +77424.92
         +0.00            +0.00             +0.00            +0.00             +0.00
         +0.00            +0.00             +0.00            +0.00             +0.00
         +0.00            +0.00             +0.00            +0.00             +0.00
REACTION LOADS (APPROX)
         +0.00            +0.00             +0.00            +0.00             +0.00
         +0.00            +0.00             +0.00            +0.00             +0.00
     +19657.66        -22939.01         +92051.67        -34042.51         +77424.92
         +0.00            +0.00             +0.00            +0.00             +0.00
         +0.00            +0.00             +0.00            +0.00             +0.00
         +0.00            +0.00             +0.00            +0.00             +0.00
APPROXIMATE LOADS
         +0.00          +565.33          -1363.06            +0.00          -6644.03
       +632.26          +243.28          -1558.98          -501.34           -729.10
     -33080.60        +36488.10        -152327.43        +55572.14        -112599.50
       +211.95           -83.80           +328.49          +742.71          +1581.43
        +91.90          -235.47           +737.05          -990.44         -19216.20
       -719.43          -233.04           -636.16          -980.25          +2379.70
ACTUAL LOADS
        -35.85          +625.81          -1374.78          +853.12          -6442.88
       +683.47          +171.14          -1191.99          -336.29           -975.78
     -36497.38        +50194.60        -159776.41        +74923.81        -117478.82
       -504.64         +1971.70          -1292.09         +3301.68           +347.48
        -24.84           -99.33           -184.33         +2306.44         -19414.17
       -773.98          +151.44           -686.86          -756.36          +2329.64
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CURRENT READING       15
RAW STRAIN DATA
           +1.06           +.06          +18.37           +2.44          +20.22
           +1.06          +2.79          +12.77           +2.44           -8.49
           +3.46          +7.85           +7.16           -2.55          -10.43
           -2.85          +1.49          -10.33           +1.21          +49.34
           -1.88          +1.16           -8.51           +4.98          +58.73
           -1.64           +.02           -4.86            -.77          -65.09
           -4.77          -1.11           -7.37           -6.52          -49.96
SHEAR FORCES
         +188.29         +10.95        +3275.43         +434.65        +3605.32
         +188.29        +497.63        +2276.14         +434.65        -1512.92
         +616.62       +1399.34        +1276.85         -455.10        -1860.02
         -507.40        +264.91        -1840.98         +216.06        +8796.66
         -334.46        +206.26        -1516.21         +887.23       +10470.43
         -291.95          +4.39         -865.80         -137.92       -11603.33
         -849.83        -197.48        -1314.28        -1163.07        -8906.34
SHEAR DIFFERENCES
           +0.00        +486.68         -999.29           +0.00        -5118.24
         +428.33        +901.71         -999.29         -889.75         -347.10
        -1124.02       -1134.43        -3117.83         +671.16       +10656.68
         +172.94         -58.66         +324.77         +671.16        +1673.77
          +42.51        -201.87         +650.41        -1025.15       -22073.77
         -557.88        -201.87         -448.47        -1025.15        +2696.99
REACTION LOADS (ACTUAL)
           +0.00          +0.00           +0.00           +0.00           +0.00
           +0.00          +0.00           +0.00           +0.00           +0.00
       +19957.12      -17466.68       +93136.89       -24984.51       +77914.76
           +0.00          +0.00           +0.00           +0.00           +0.00
           +0.00          +0.00           +0.00           +0.00           +0.00
           +0.00          +0.00           +0.00           +0.00           +0.00
REACTION LOADS (APPROX)
           +0.00          +0.00           +0.00           +0.00           +0.00
           +0.00          +0.00           +0.00           +0.00           +0.00
       +19957.12      -17466.68       +93136.89       -24984.51       +77914.76
           +0.00          +0.00           +0.00           +0.00           +0.00
           +0.00          +0.00           +0.00           +0.00           +0.00
           +0.00          +0.00           +0.00           +0.00           +0.00
APPROXIMATE LOADS
           +0.00        +644.93        -1324.64           +0.00        -6657.84
         +639.80       +1366.83        -1515.04        -1348.69         -518.47
       -33710.06      +26250.89      -154714.51       +41236.47      -107549.85
         +235.94         -81.85         +453.42         +936.57        +2283.50
          +56.50        -275.50         +888.26        -1399.10       -29337.64
         -737.38        -272.67         -606.05        -1384.70        +3564.73
ACTUAL LOADS
          -41.08        +711.36        -1353.89         +840.18        -6417.06
         +547.45       +1299.24        -1180.71        -1187.73         -822.52
       -36428.52      +40128.31      -160379.11       +60324.28      -111389.81
         -377.61       +1916.73         -913.64        +3276.06        +1003.85
          -50.45        -172.18         -225.37        +3464.06       -29428.62
         -775.74         +93.15         -569.69        -1254.19        +3564.64
```

```
CURRENT READING      16
RAW STRAIN DATA
        +.54           -.88          +17.82           -3.21          +39.09
        +.54          +1.32          +11.42           -3.21          -10.48
       +2.52          +2.88           +5.03            +.29          -11.04
       -2.23          +2.30           -7.08           +1.81           -7.82
       -1.24          +1.71           -6.57           +3.34           -7.12
        -.85           +.80           -4.50           +1.98           -4.27
       -4.01           -.10           -7.28            +.62           -3.65
SHEAR FORCES
      +95.85        -157.74        +3176.02         -572.99        +6969.27
      +95.85        +235.45        +2036.15         -572.99        -1867.54
     +449.67        +512.59         +896.29          +50.98        -1967.26
     -398.25        +409.41        -1263.00         +323.22        -1394.78
     -220.43        +304.09        -1171.17         +595.45        -1269.88
     -151.28        +142.88         -801.91         +353.19         -761.15
     -714.21         -18.34        -1298.61         +110.92         -650.62
SHEAR DIFFERENCES
       +0.00        +393.19        -1139.87           +0.00        -8836.81
     +353.82        +277.14        -1139.87         +623.97          -99.72
     -847.92        -103.18        -2159.29         +272.24         +572.48
     +177.82        -105.31          +91.84         +272.24         +124.89
      +69.15        -161.22         +369.25         -242.27         +508.73
     -562.93        -161.22         -496.70         -242.27         +110.53
REACTION LOADS (ACTUAL)
       +0.00          +0.00           +0.00           +0.00           +0.00
       +0.00          +0.00           +0.00           +0.00           +0.00
   +17453.60      -25988.58       +91096.81       -47493.15       +90822.76
       +0.00          +0.00           +0.00           +0.00           +0.00
       +0.00          +0.00           +0.00           +0.00           +0.00
       +0.00          +0.00           +0.00           +0.00           +0.00
REACTION LOADS (APPROX)
       +0.00          +0.00           +0.00           +0.00           +0.00
       +0.00          +0.00           +0.00           +0.00           +0.00
   +17453.60      -25988.58       +91096.81       -47493.15       +90822.76
       +0.00          +0.00           +0.00           +0.00           +0.00
       +0.00          +0.00           +0.00           +0.00           +0.00
       +0.00          +0.00           +0.00           +0.00           +0.00
APPROXIMATE LOADS
       +0.00        +521.04        -1510.99           +0.00       -11494.99
     +528.50        +420.09        -1728.17         +945.83         -148.96
   -29265.27      +41605.72      -149894.68       +76773.50      -144315.81
     +242.59        -146.96         +128.21         +379.89         +170.39
      +91.90        -220.02         +504.29         -330.64         +676.15
     -744.05        -217.76         -671.21         -327.24         +146.09
ACTUAL LOADS
      -31.69        +606.00        -1586.01        +1560.99       -11360.67
     +549.74        +403.55        -1607.43        +1215.25         -472.88
   -33053.46      +55003.95      -159432.06       +98299.95      -150776.26
     -524.91       +1943.45        -1803.87        +3552.02         -869.00
      -11.34         -92.36            -.80         -153.73         +242.11
     -805.76        +190.24         -845.64          +75.39          +18.88
```

```
CURRENT READING      17
RAW STRAIN DATA
        +.65         -.58        +18.19         -1.27        +65.32
        +.65        +1.58        +11.86         -1.27        -30.89
       +2.86        +3.02         +5.54          +.84        -20.92
       -2.32        +1.98         -7.92         +1.99         -7.33
       -1.34        +1.53         -6.94         +3.14         -6.53
        -.93         +.49         -4.95         +1.81         -3.36
       -4.13         -.55         -7.63          +.47         -2.87
SHEAR FORCES
     +115.87      -103.95      +3243.40       -225.85     +11644.79
     +115.87      +281.93      +2115.10       -225.85      -5506.90
     +509.38      +537.48       +986.81       +149.34      -3729.58
     -413.39      +352.31      -1411.50       +354.81      -1307.21
     -238.88      +272.06      -1236.45       +560.29      -1163.34
     -165.91       +87.08       -883.21       +322.29       -597.59
     -737.02       -97.90      -1359.89        +84.29       -511.00
SHEAR DIFFERENCES
       +0.00      +385.88      -1128.29         +0.00     -17151.87
     +393.51      +255.55      -1128.29       +375.20      +1777.32
     -922.77      -185.17      -2398.31       +205.47      +2422.37
     +174.51       -80.25       +175.05       +205.47       +143.87
      +72.98      -184.98       +353.23       -238.00       +563.75
     -571.11      -184.98       -476.68       -238.00        +88.59
REACTION LOADS (ACTUAL)
       +0.00        +0.00         +0.00         +0.00         +0.00
       +0.00        +0.00         +0.00         +0.00         +0.00
   +17819.69    -23587.13     +90836.82     -37105.47    +110149.45
       +0.00        +0.00         +0.00         +0.00         +0.00
       +0.00        +0.00         +0.00         +0.00         +0.00
       +0.00        +0.00         +0.00         +0.00         +0.00
REACTION LOADS (APPROX)
       +0.00        +0.00         +0.00         +0.00         +0.00
       +0.00        +0.00         +0.00         +0.00         +0.00
   +17819.69    -23587.13     +90836.82     -37105.47    +110149.45
       +0.00        +0.00         +0.00         +0.00         +0.00
       +0.00        +0.00         +0.00         +0.00         +0.00
       +0.00        +0.00         +0.00         +0.00         +0.00
APPROXIMATE LOADS
       +0.00      +511.35      -1495.64         +0.00     -22311.32
     +587.79      +387.37      -1710.62       +568.73      +2654.79
   -29970.37    +37614.06    -149860.99     +59970.03    -172262.29
     +238.08      -111.98       +244.39       +286.72       +196.28
      +96.99      -252.46       +482.41       -324.82       +749.26
     -754.86      -249.86       -644.16       -321.47       +117.09
ACTUAL LOADS
      -36.15      +628.92      -1792.38      +3075.45     -22163.08
     +609.47      +377.91      -1596.63       +887.77      +1869.80
   -33465.12    +50981.17    -158041.11     +83448.23    -177568.82
     -487.76     +1929.57      -1528.83      +3668.94       -586.62
       -2.03      -140.99         -5.69       -227.99       +269.68
     -807.66      +151.74       -801.61        +95.08         -1.34
```

```
CURRENT READING      18
RAW STRAIN DATA
             +.71          -.26        +18.58          +.26        +84.39
             +.71         +1.85        +12.27          +.26        -45.38
            +3.13         +3.53         +5.97         +1.07        -27.90
            -2.53         +1.65         -8.37         +2.05         -6.92
            -1.58         +1.33         -7.57         +3.04         -6.15
            -1.15          +.05         -5.42         +1.66         -2.93
            -4.29         -1.23         -8.02          +.28         -2.38
SHEAR FORCES
          +126.14        -45.80      +3312.51        +46.08     +15043.24
          +126.14       +330.50      +2188.22        +46.08      -8089.88
          +558.48       +629.05      +1063.94       +190.43      -4974.15
          -450.47       +294.33      -1491.58       +366.13      -1233.05
          -281.54       +237.42      -1348.91       +541.83      -1095.62
          -205.43         +8.74       -965.56       +296.26       -522.65
          -764.87       -219.93      -1430.40        +50.69       -424.48
SHEAR DIFFERENCES
            +0.00       +376.30      -1124.29         +0.00     -23133.12
          +432.34       +298.55      -1124.29       +144.35      +3115.73
         -1008.95       -334.72      -2555.52       +175.70      +3741.11
          +168.94        -56.92       +142.67       +175.70       +137.43
           +76.11       -228.68       +383.35       -245.57       +572.97
          -559.45       -228.68       -464.84       -245.57        +98.17
REACTION LOADS (ACTUAL)
            +0.00         +0.00         +0.00         +0.00         +0.00
            +0.00         +0.00         +0.00         +0.00         +0.00
        +18264.79     -20763.86     +91415.19     -29641.71    +125120.39
            +0.00         +0.00         +0.00         +0.00         +0.00
            +0.00         +0.00         +0.00         +0.00         +0.00
            +0.00         +0.00         +0.00         +0.00         +0.00
REACTION LOADS (APPROX)
            +0.00         +0.00         +0.00         +0.00         +0.00
            +0.00         +0.00         +0.00         +0.00         +0.00
        +18264.79     -20763.86     +91415.19     -29641.71    +125120.39
            +0.00         +0.00         +0.00         +0.00         +0.00
            +0.00         +0.00         +0.00         +0.00         +0.00
            +0.00         +0.00         +0.00         +0.00         +0.00
APPROXIMATE LOADS
            +0.00       +498.66      -1490.33         +0.00     -30091.74
          +645.78       +452.55      -1704.55       +218.81      +4653.98
        -30819.90     +32835.85    -151043.31     +47925.65    -194093.02
          +230.48        -79.42       +199.19       +245.18       +187.49
          +101.15       -312.09       +523.55       -335.15       +761.52
          -739.45       -308.88       -628.16       -331.70       +129.75
ACTUAL LOADS
           -38.61       +641.53      -1945.13      +4163.27     -29932.65
          +656.47       +448.65      -1599.20       +576.65      +3548.88
        -33975.27     +46295.17    -158124.57     +73008.20    -198576.81
          -453.11      +1958.56      -1452.42      +3827.74       -419.88
           +11.22       -226.06        +48.11       -295.33       +245.87
          -778.81        +83.69       -763.74        +91.47        +18.79
```

Transport Canada — Transports Canada

Development — Développement

TP 6045E

Measurement of Ice Forces on Fishing Vessels

Summary Report

Prepared for

Transportation Development Centre

JULY 1984

Canada

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ARCTEC CANADA LIMITED 1338C

MEASUREMENT OF ICE FORCES ON FISHING VESSELS

SUMMARY REPORT

TP 6045E

July 1984

by

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Submitted to

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AVIS

Ce rappart est également disponible en français.

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17. Abstract

A study has been conducted to investigate ice forces on fishing vessels. An instrumentation system, consisting of an array of 35 strain gauge pairs, was fitted into the bow of National Sea Products' "CAPE BRIER". The system monitored shear stress in the main frames of the instrumented panel and gathered data during significant impacts with ice. Data were converted to ice loads through an algorithm developed from finite element modelling and checked through a physical calibration. The maximum recorded ice pressure during a week of operating in ice was 644 kPa. Statistical analysis of the data indicates that potentially hazardous loads could be expected during the lifetime of the vessel.

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16. Agent de projet — CDT
Ian M. Bayly

17. Résumé

Ce rapport concerne l'étude des efforts exercés par les glaces sur la coque des bateaux de pêche. A cette fin, un réseau de 35 paires de jauges extensométriques a été disposé sur une partie de la proue du CAPE BRIER, un bateau appartenant à National Sea Products. Il s'agissait de mesurer les contraintes de cisaillement dans les membrures du bateau et d'enregistrer le comportement de la coque sous l'impact de gros blocs de glace. La conversion des données en charges a été faite à l'aide d'un algorithme de modélisation par la méthode des éléments finis et les résultats ont été validés par étalonnage des éléments de mesure. La pression maximum enregistrée en une semaine a été de 644 kPA; l'analyse statistique des données a révélé qu'un bateau de pêche risquait de subir des impacts de niveau critique durant sa vie utile.

18. Mots-clés
Glace de mer, charges, efforts, coques, navires, bateaux de pêche

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FOREWORD

Fishing vessels regularly navigate the ice pack off the coast of Newfoundland and Labrador. Normally the pack is open, although it can form a solid cover. There are many significant differences between fishing vessels and icebreakers for which ice loads have been measured in the past. In this study, for the first time, a system has been developed to investigate ice loads on fishing vessels by monitoring the strains in the hull. The findings have enabled a partial understanding of the phenomena.

This summary report has been extracted from the final report of the same title. For the purposes of clarity the figure numbers given here are the same as those in the main report.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. SURVEY OF DAMAGE TO FISHING VESSELS 2

3. DESCRIPTION OF OPERATING ENVIRONMENT AND SHIP PARAMETERS 5

4. DESCRIPTION OF INSTRUMENTED LOAD PANEL 8

5. ICE CONDITIONS DURING TESTING 11

6. ANALYSIS OF ICE LOAD DATA 13

7. CONCLUSIONS 17

8. RECOMMENDATIONS 18

1. INTRODUCTION

A system has been developed and implemented to allow the measurement of ice loads on a fishing vessel - National Sea Product's 'CAPE BRIER'. The system consists of an array of 35 strain gauges in the starboard bow dry tank, connected to an electronics package and a computer on the bridge. The system constantly monitors the gauges until a threshold is exceeded, at which time it collects five minutes of peak data.

The system was installed and calibrated, between voyages, at NSP's Lunnenberg facility. Due to a variety of circumstances (including a gas well blowout and a ship in distress) the system was only deployed in ice once. On that deployment valuable data was collected during a seven day period in ice. Eighty-six five-minute data records were obtained, with a peak pressure of 644 kPa.

This report contains a complete description of the system, the calibration, the data collected, logs of the ice conditions and analysis of the data. Recommendations for further development and testing are made.

2. SURVEY OF DAMAGE TO FISHING VESSELS

Data was collected on ice damage to fishing vessels so that the most effective location for installation of strain gauges could be determined. The data indicated that sixty percent of ice damage occurs within thirty-five percent of the ship's length from the bow (See Figure 2.1), indicating that the instrumentation system should be in the bow, rather than in the midbody or stern.

Seventy-eight percent of ice damage to fishing vessels involves bent or buckled structure, with no penetration, and is therefore minor in nature. Another fourteen percent of the damage involves some type of fracture and leaking. Six percent involves rudder damage, while only two percent involves loss of the vessel. Figure 2.2 illustrates these data.

FIGURE 2.1 LOCATION OF ICE DAMAGE TO FISHING VESSELS

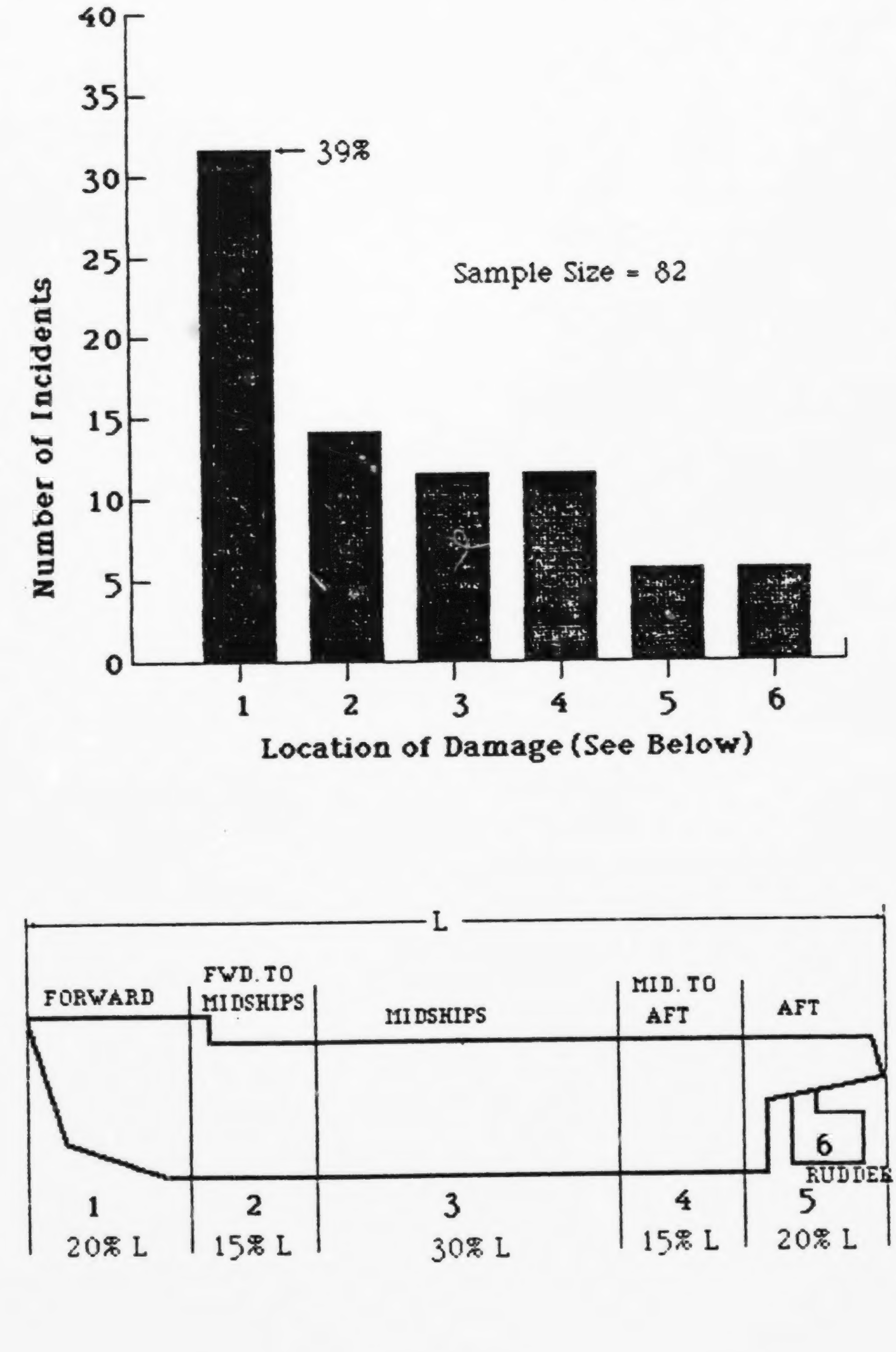
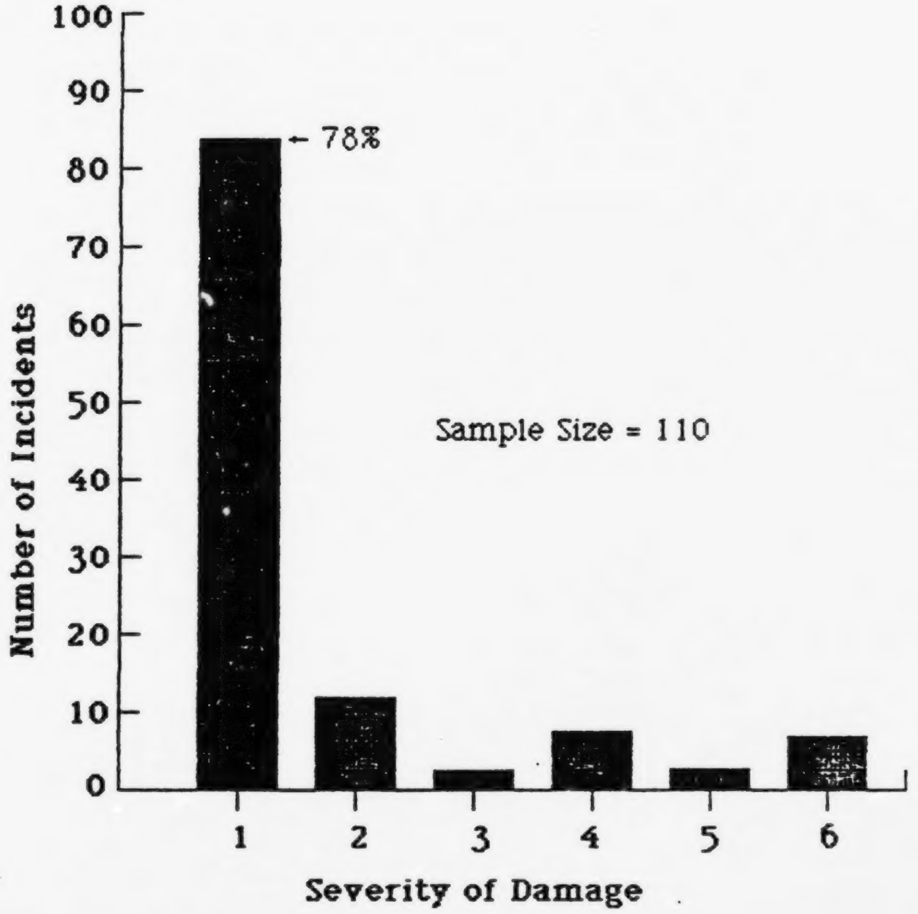


FIGURE 2.2 SEVERITY OF ICE DAMAGE TO FISHING VESSELS



1 = Bent, Buckled or Indented
2 = Cracked or Fractured
3 = Leaking, Porous
4 = Torn, Holed or Collapsed
5 = Missing or Lost
6 = Rudder Damage (Twisted,Bent,Buckled or Indented)

3. DESCRIPTION OF OPERATING ENVIRONMENT AND SHIP PARAMETERS

The test location lies approximately 250 miles off the coast of northern Newfoundland and southern Labrador, along the outer edge of the Grand Banks. The major climatic influences on the area are the westerly circulation bringing relatively warm air from the continent and the cold Labrador current, coming south from Baffin Bay.

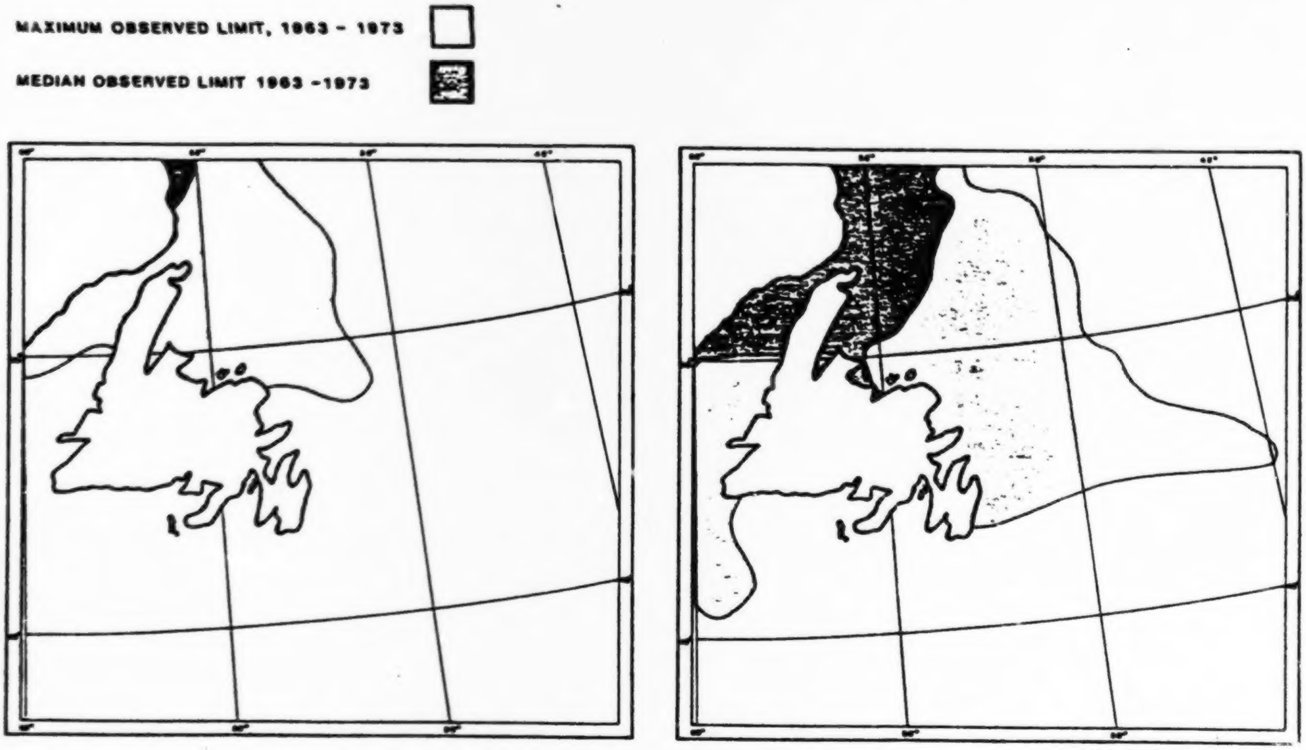
Typical weather during the March to May time period consists of 2° to 5°C mean temperature, 15 to 20 knot westerly winds, with poor visibility (<0.5 n mi.) for 15% of the time. Mean wave heights range from 1.5 to 2.2 meters, in open water.

The test region is subject to sea ice during the winter and spring and to icebergs year round. Figure 3.3 illustrates the mean and maximum sea ice limits in the region. During the winter the pack is composed mainly of locally formed ice up to thicknesses of 1.4 m. In the spring older floes from the Arctic drift into the test region. Traces of multi-year ice can be expected with the Arctic ice in the late spring.

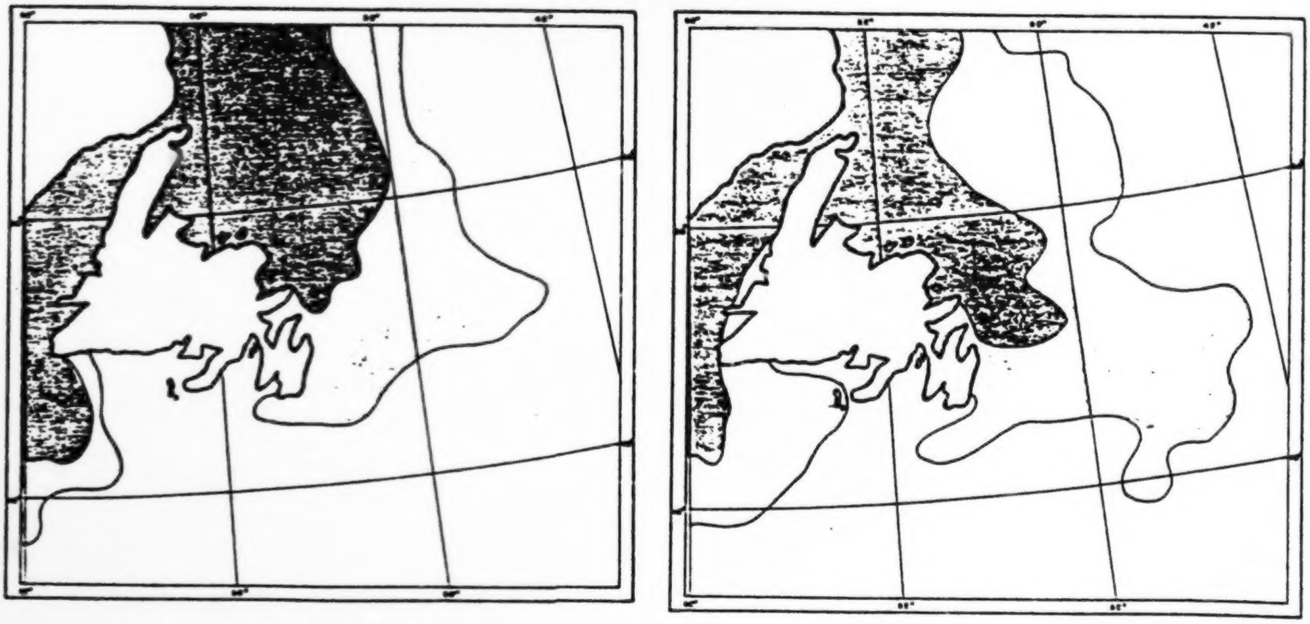
The vessel chosen for instrumentation was the MV CAPE BRIER, a 50 metre stern trawler whose main particulars are indicated in Table 3.2.

FIGURE 3.3

SEA ICE LIMITS in PROJECT REGION


MAXIMUM OBSERVED LIMIT, 1963 - 1973 ☐
MEDIAN OBSERVED LIMIT 1963 -1973 ▨

December 25 **January 29**



February 26 **March 26**

AFTER MARKHAM, 1980

TABLE 3.2
GENERAL PARTICULARS OF THE CAPE BRIER

LENGTH OVERALL	49.9 m
LENGTH BP	42.0 m
BEAM MOULDED	11.80 m
DRAUGHT	4.13 m (worst operating)
DISPLACEMENT	1123 tonnes
BLOCK COEFFICIENT	.55
POWER	2000 BHP
SPEED (TRIAL)	13.5 knots
CLASSIFICATION	LR 100A1 + LMC (Hull = 1A Super)

4. DESCRIPTION OF INSTRUMENTED LOAD PANEL

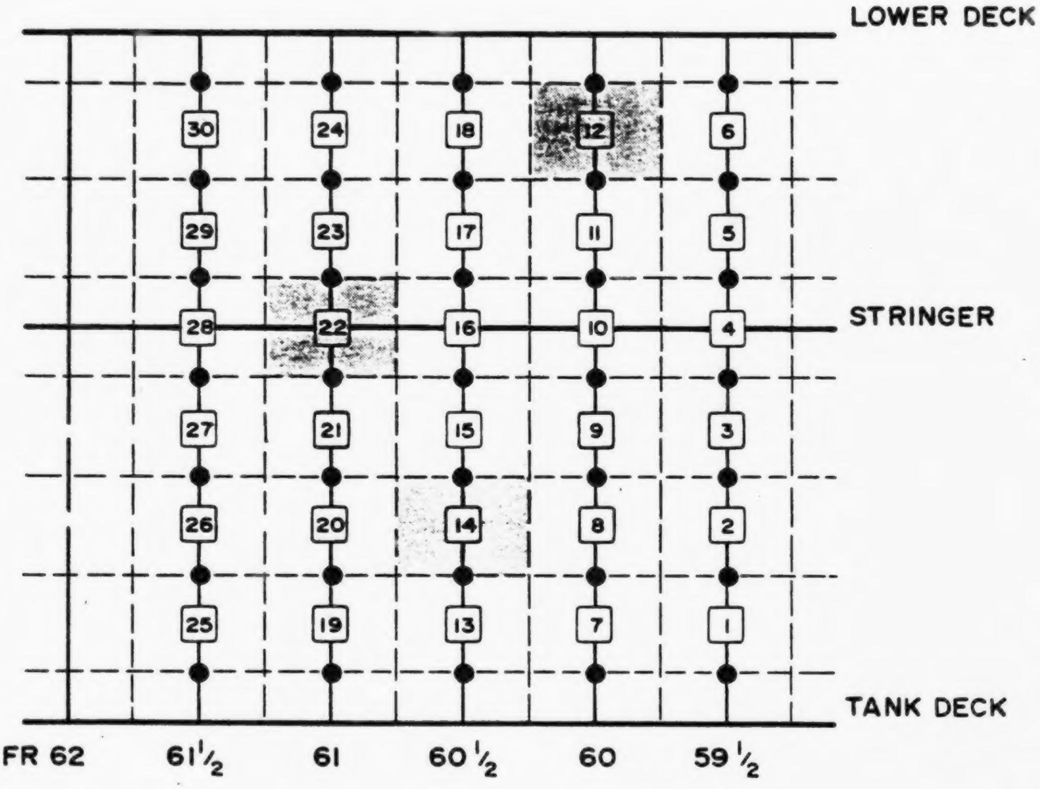
The location of the instrumented panel was based on the damage survey and on the results of Arctec's ice load computer program, ILOAD. Both indicated that the bow of the ship, in particular the 'dry tank', would be both suitable and accessible for instrumentation.

The instrumented panel is shown in Figure 5.2. Thirty-five strain gauge pairs are used to define thirty sub-panels. The ice load on each sub-panel is proportional to the shear force difference across the sub-panel (shear above minus shear below) is proportional to the ice force on the sub-panel. A finite element model of the panel along with a physical calibration was used to establish the factors to convert from measured strain to actual ice load.

The data acquisition hardware is illustrated in Figure 5.3. A Z80 microprocessor and peripheral equipment are housed in the 'dry tank' to actually gather and transmit the strain data. An HP85B computer on the bridge receives data from the Z80, analyzes, displays and stores the data on a cassette tape.

FIGURE 5.2

PANEL GAUGING PATTERN and RESULTING INFLUENCE AREAS


LOWER DECK
STRINGER
TANK DECK
30
24
18
12
6
29
23
17
11
5
28
22
16
10
4
27
21
15
9
3
26
20
14
8
2
25
19
13
7
1
FR 62
61½
61
60½
60
59½

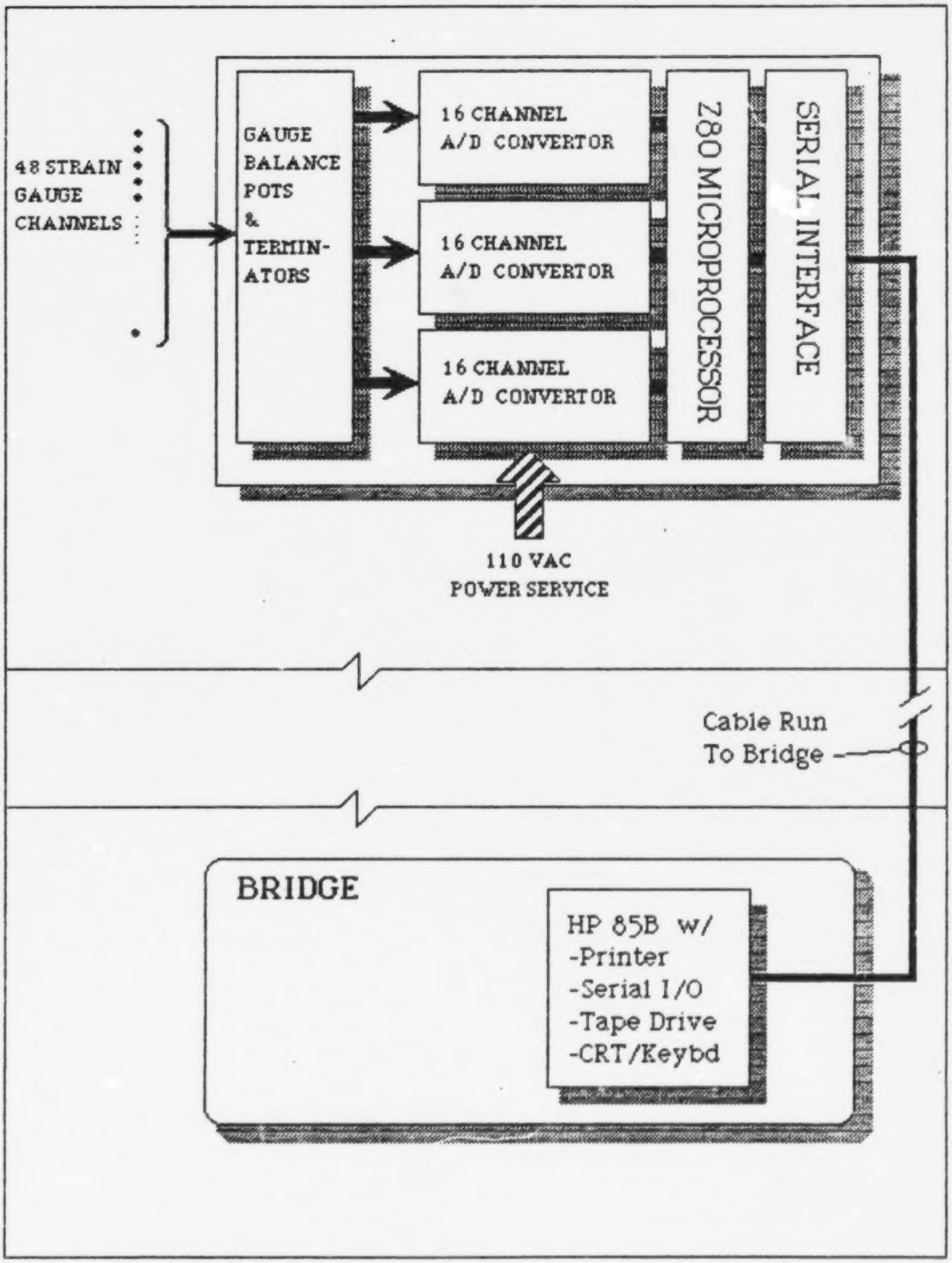
▨ TYPICAL INFLUENCE PANEL (SUB PANEL)

● GAUGE ROSETTES ON FRAME

1 INFLUENCE AREA NUMBER

FIGURE 5.3

DATA ACQUISITION HARDWARE LAYOUT

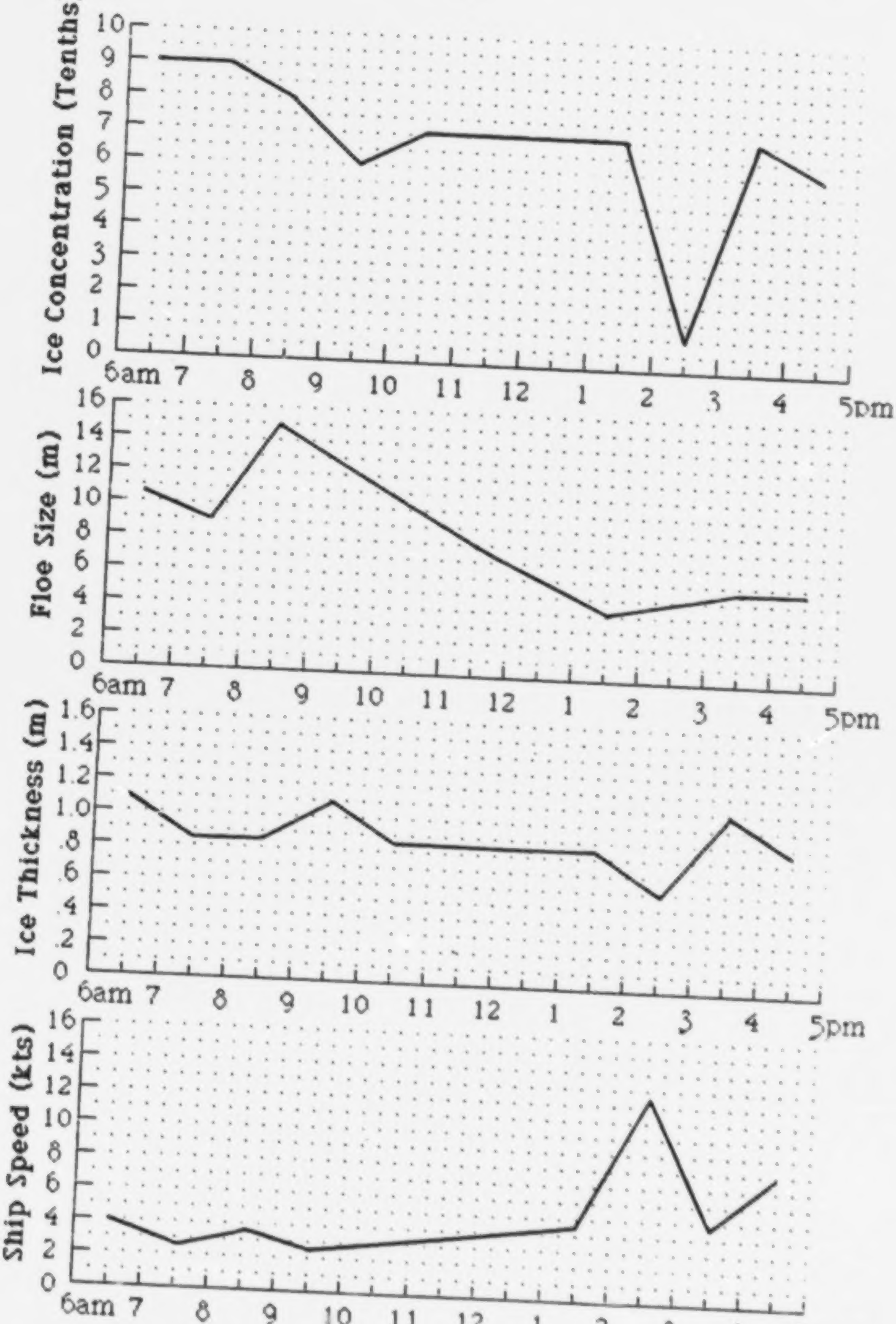

48 STRAIN GAUGE CHANNELS
GAUGE BALANCE POTS & TERMIN-ATORS
16 CHANNEL A/D CONVERTOR
16 CHANNEL A/D CONVERTOR
16 CHANNEL A/D CONVERTOR
Z80 MICROPROCESSOR
SERIAL INTERFACE
110 VAC POWER SERVICE
Cable Run To Bridge
BRIDGE
HP 85B w/
-Printer
-Serial I/O
-Tape Drive
-CRT/Keybd

5. ICE AND ENVIRONMENTAL CONDITIONS DURING TESTING

Ice and environmental conditions were recorded hourly during ice operations. Navigation data, meteorological data, oceanographic data and ice data were recorded. Figure 8.7 shows a typical presentation of ice data and ship speed during the course of a day. Note the dependence of ship speed on concentration. During the week, ice concentration ranged from 0/10 to 10/10, but was typically 7/10. Ice thickness was typically 1.1 m, with floe size typically 10 m, as estimated from photographs.

Temperatures were around 0°C, with some fog and rain. Winds were light and sea state was low.

Figure 8.7 SHIP'S LOG DATA
March 21



6. ANALYSIS OF ICE LOAD DATA

Data was gathered in 5-minute segments. When strain exceeded a threshold of 50 microstrain, a complete set of readings over a 5-minute period were taken. During the 7 days in ice, 86 5-minute 'events' were recorded.

The maximum single sub-panel pressure was 644 kPa (= 93 psi). As area increased the average pressure decreased. The highest average pressure on 9 sub-panels was 130 kPa (= 19 psi).

Ice loads are random processes. All the data from the 86 events were analyzed using the methods of extreme value statistics, in order to be able to predict highest expected loads over the lifetime of the ship. Figure 9.12 shows the measured data plotted on Type I extreme value probability paper. The dashed lines represent a Type I equation as a function of area:

$$F\,(p) = e^{-e^{-\alpha(A)\,(P\,-\,u(A))}}$$

where:

$F\,(p)$ = probability of not exceeding p

p = ice pressure (MPa)

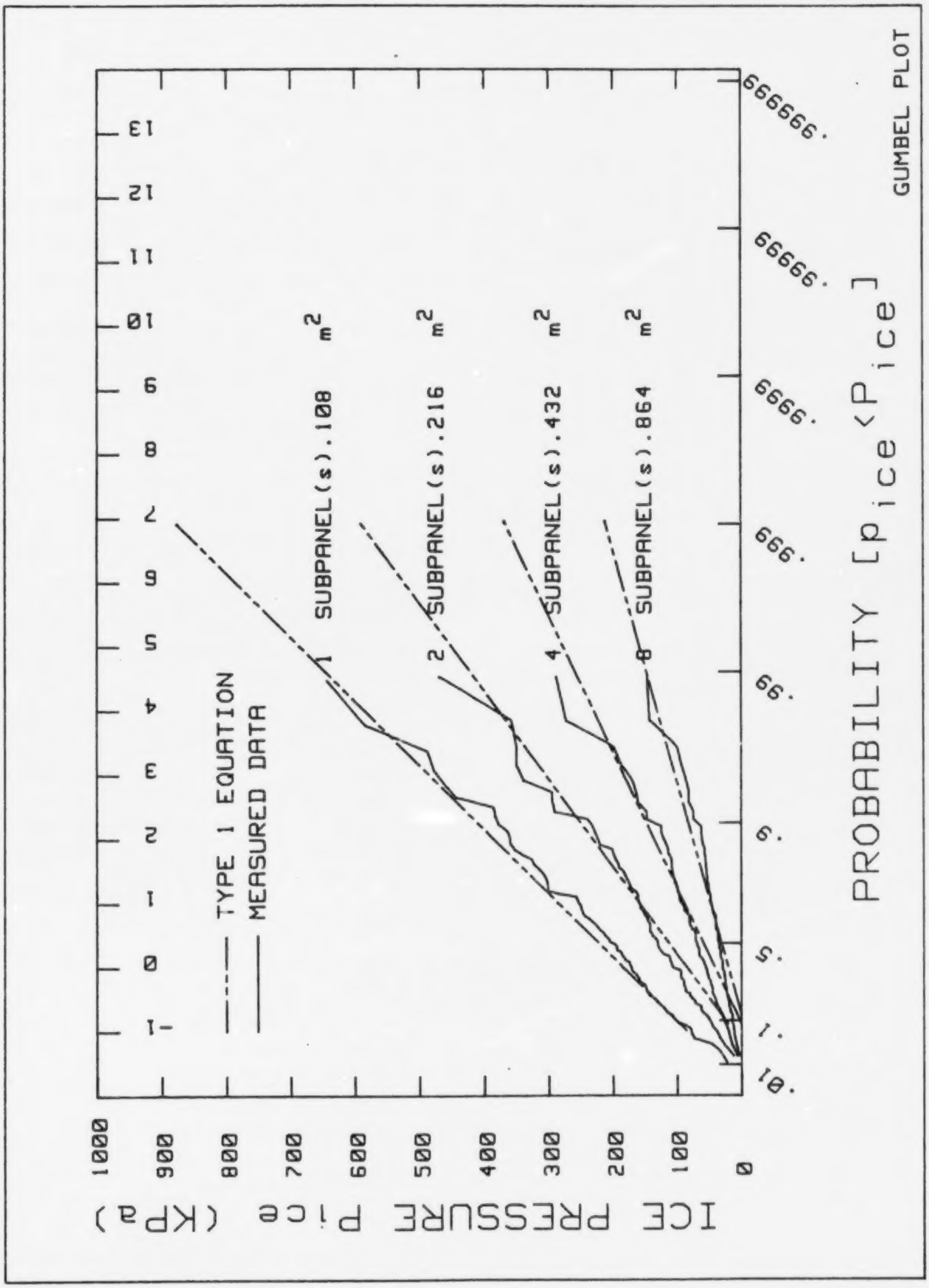
$\alpha(A) = 35.1\ A + 6.20$

$u(A) = .02/A$

A = area (m²)

FIGURE 9.12

GUMBEL TYPE I EXTREME VALUE
STATISTICS



The equation fits the data reasonably well for the single sub-panel, but is less appropriate for eight sub-panels. A change in the nature of ice forces with increasing area alters both the magnitude and form of the resulting statistics. The larger areas appear to be governed by a Type II extreme value equation rather than a Type I. This is probably because local pressures are dependent on local crushing processes, while larger area pressures are governed by the total force which is dependent on the cusp breaking process. The data raises many questions concerning the nature of the statistics and the nature of the failure process itself.

The eventual goal of this work is to establish design ice pressures for fishing vessels. To do this, the data must be extrapolated over longer time periods. The main problem with the limited data is that the Type I and Type II equations extrapolate to very different values. The predicted 20-year single sub-panel pressure is 1250 kPa (=181 psi) if Type I is used and 6500 kPa (=942 psi) if Type II is used.

The expected stress levels, as a percentage of yield stress are shown in Figure 9.16. These numbers assume a Type I probability distribution. The probability of .01% is roughly equivalent to ten weeks of operations in ice.

FIGURE 9.16 Expected Stresses as a Percentage of Yield Stress for Measured and Projected Loads

LOAD CASE	Main Frame Bending	Shell Plate Bending	Stringer Bending
1. Peak Measured	23%	~	~
2. 1% Probability Upper Area	30%	~	~
3. 1% Probability Lower Area	40%	~	~
4. .1% Probability Lower Area	59%	~	~
5. .01% Probability Upper Area	44%	9%	13%
6. .01% Probability Lower Area	61%	7%	19%

Note: Bending Stresses Exceeded All Other Stresses

7. CONCLUSIONS

A system has been developed that can measure ice loads on fishing vessels, in particular, National Sea Products' 'CAPE BRIER'. The system represents an initial attempt in this area, and while certain problems were encountered, considerable understanding of ice loads on fishing vessels has been gained.

Data was collected during a period of seven days operating in ice. The highest single sub-panel pressure recorded was 644 kPa (area = $.108 m^2$). Ice pressures exceeded threshold levels during eighty-six five-minute sampling periods.

Statistical analysis of the ice pressures indicates that plate pressures tend to follow a Gumbel Type I extreme value distribution, while larger area pressures acting on the frames tend to follow Gumbel Type II distributions. Insufficient data exist to allow determination of rational design procedures. This is illustrated by the fact that, based on the present data, estimates of time between plate damage for the CAPE BRIER range from 1 to 100 weeks of operating in similar ice conditions.

8. RECOMMENDATIONS

The main recommendation is that the program for studying ice loads on fishing vessels continue. As key parts of the program the following items are recommended.

1. Longer term data collection, including dedicated testing.

2. A more detailed finite element model is required to better understand the shear in the webs of the frame. Only in this way can better agreement with the physical calibration be obtained.

3. Inclusive in 2., a more detailed analysis of the stringer, along with strain gauging of the stringer.

4. Extension of the instrumented area.

5. Examination of plate response both with finite element modelling and strain gauging.

6. Collection of more operational parameters to correlate with ice loads. These parameters should include ship speed, actual waterline position, ice conditions, ice properties and sea state.